

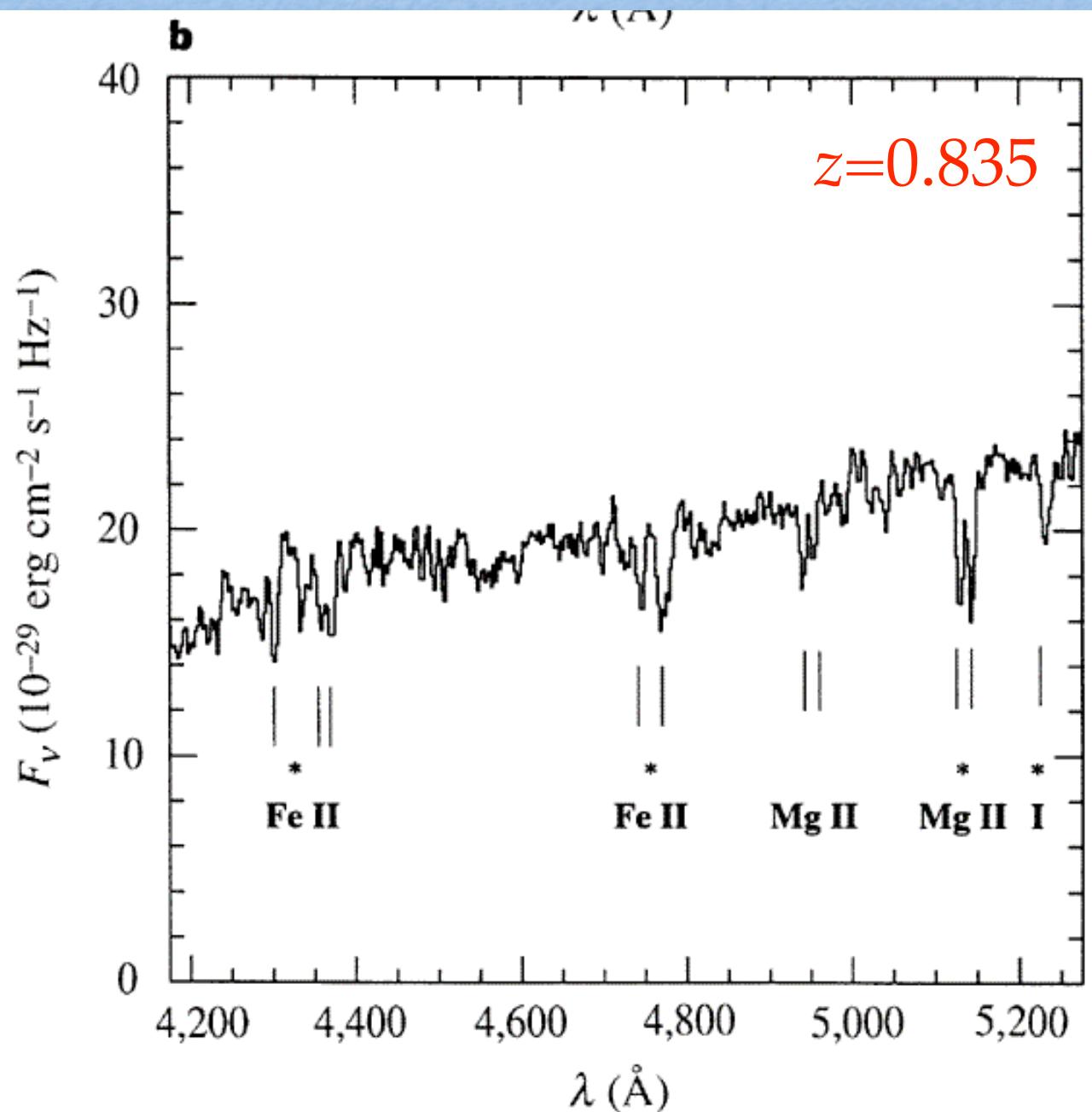
ULTRA-VIOLET ABSORBERS ALONG GRB SIGHTLINES

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European Southern Observatory, Chile

WHAT DO THEY TELL US?

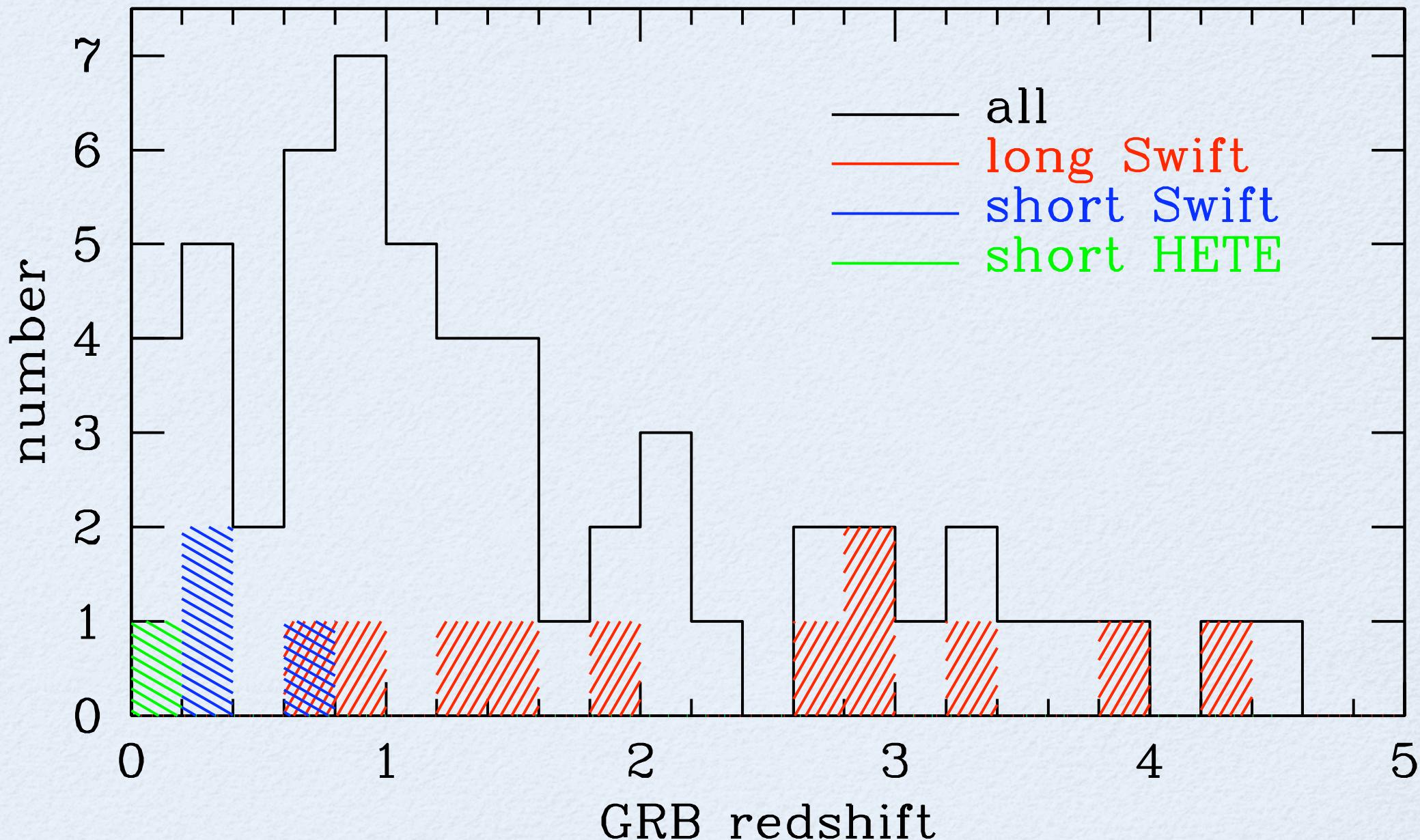
- GRB redshifts
- probe foreground absorbers (cf. QSO absorbers)
- host-galaxy DLAs: HI column densities, metallicities and fine-structure lines
- outflows in immediate environment of GRB

FIRST GRB REDSHIFT: 970508



Metzger et al. (1997)

GRB REDSHIFTS



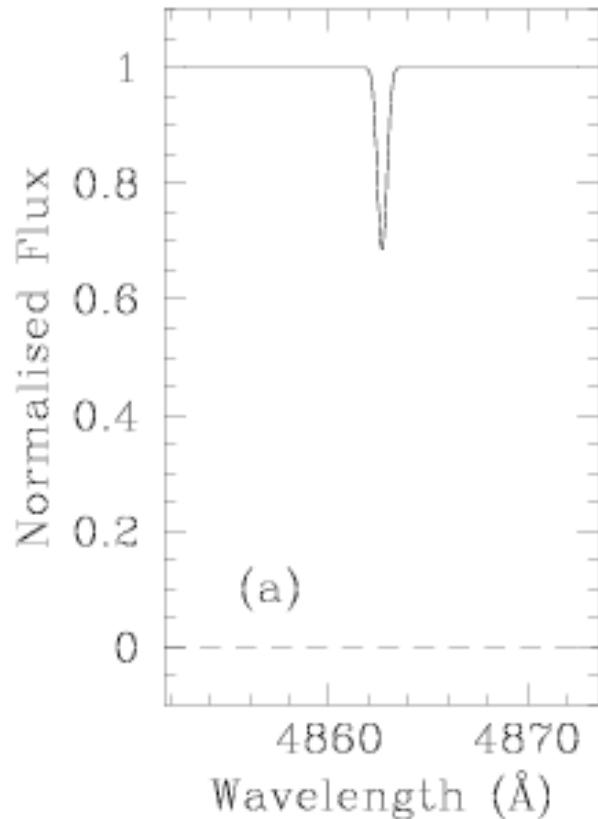
ABSORPTION LINE PROFILE

- column density and absorption cross section determine line profile $I(\nu) = I_0(\nu)e^{-\tau(\nu)}$ $\tau(\nu) = N\sigma(\nu)$
- natural broadening: absorption by single particle is not a sharp delta function ($\Delta E \Delta t \sim \hbar$)
---> Lorentzian profile $\sigma_L(\nu) = \left(\frac{\pi e^2}{m_e c}\right) f \frac{\Gamma/4\pi^2}{(\nu - \nu_0)^2 + (\Gamma/4\pi)^2}$
- doppler broadening: particles move around
---> Gaussian profile $b = \sqrt{b_{thermal}^2 + b_{bulk}^2}$
- convolution of Lorentzian and Gaussian results in Voigt profile $\sigma(\nu) = \frac{\sqrt{\pi}e^2 f}{m_e c} \frac{H(a, u)}{\Delta\nu}$

EQUIVALENT WIDTH

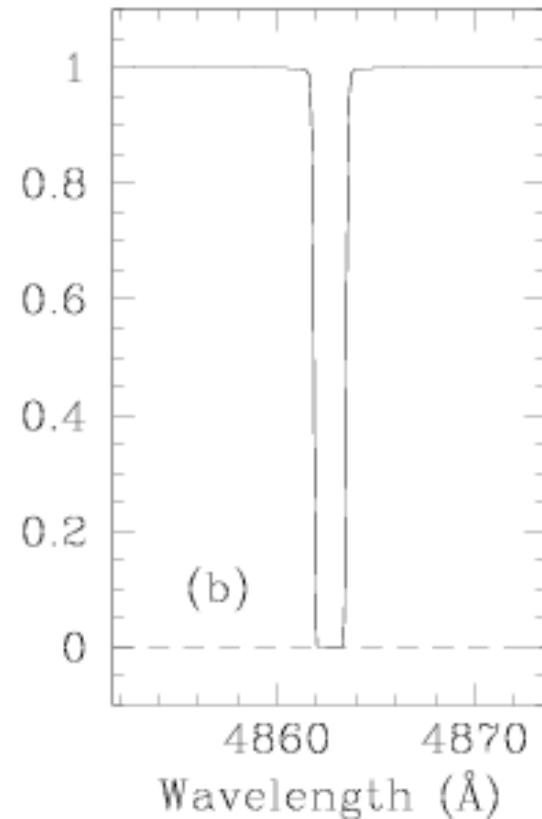
$$W(\lambda) = \int \frac{I_0 - I(\lambda)}{I_0} d\lambda = \int (1 - e^{-\tau(\lambda)}) d\lambda$$

weak or linear



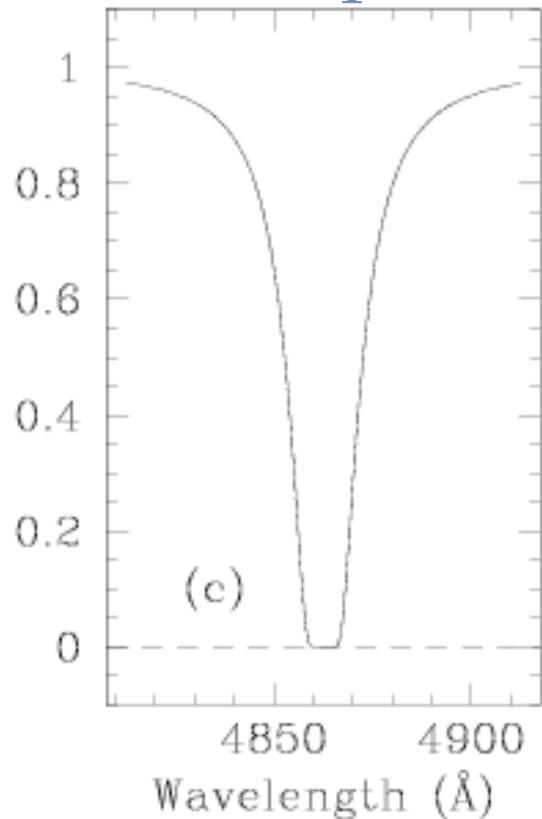
(a)

saturated



(b)

damped



(c)

$$W(\lambda) = \frac{\pi e^2 \lambda_0}{m_e c^2} N \lambda_0 f$$

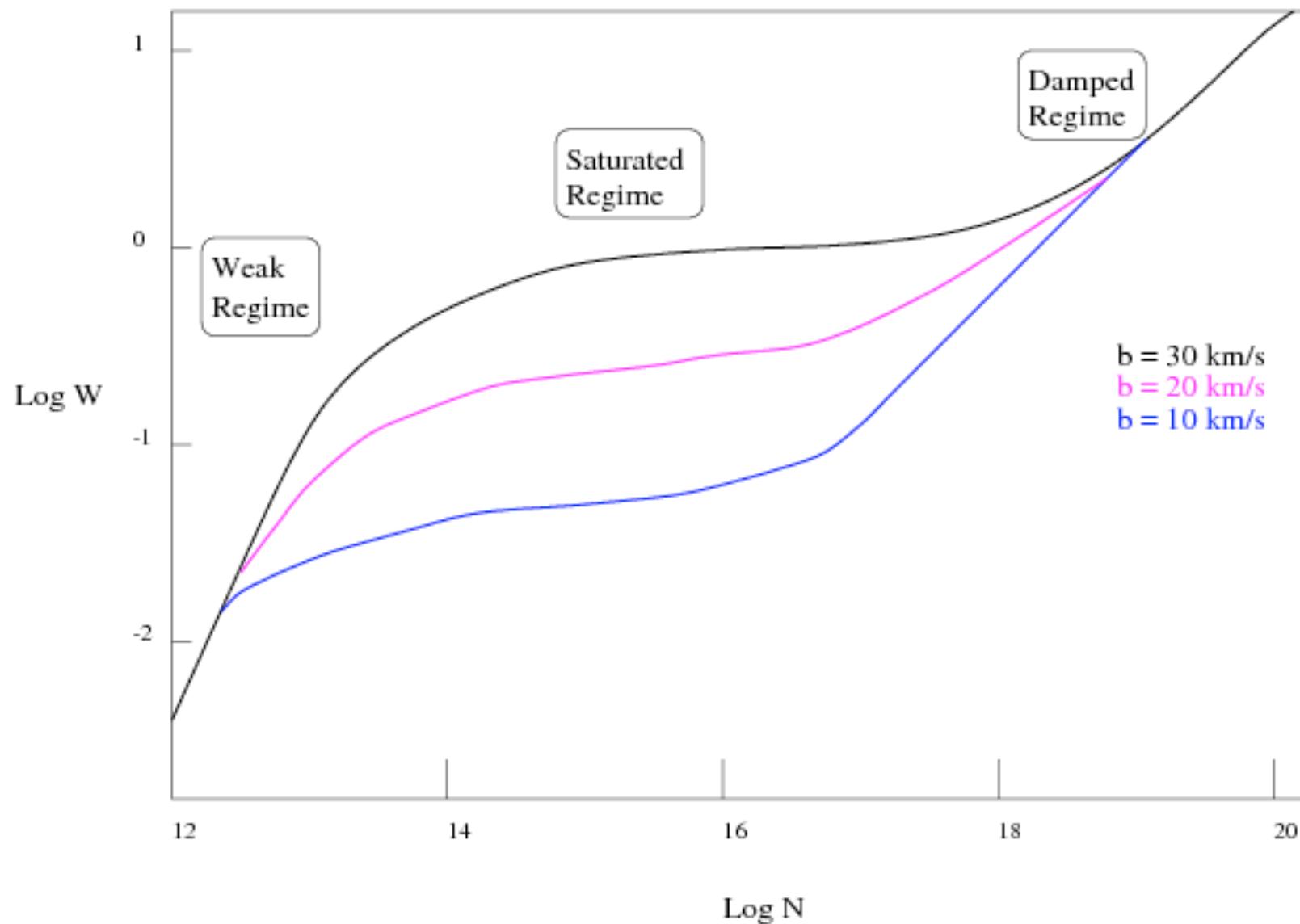
$$W(\lambda) \sim \frac{2b\lambda_0}{c} \sqrt{\ln \left(\frac{\pi^{0.5} e^2 N \lambda_0 f}{m_e c b} \right)}$$

$$W(\lambda) \sim \frac{\lambda_0^{1.5}}{c} \sqrt{\frac{e^2}{m_e c} N \lambda_0 f \Gamma}$$

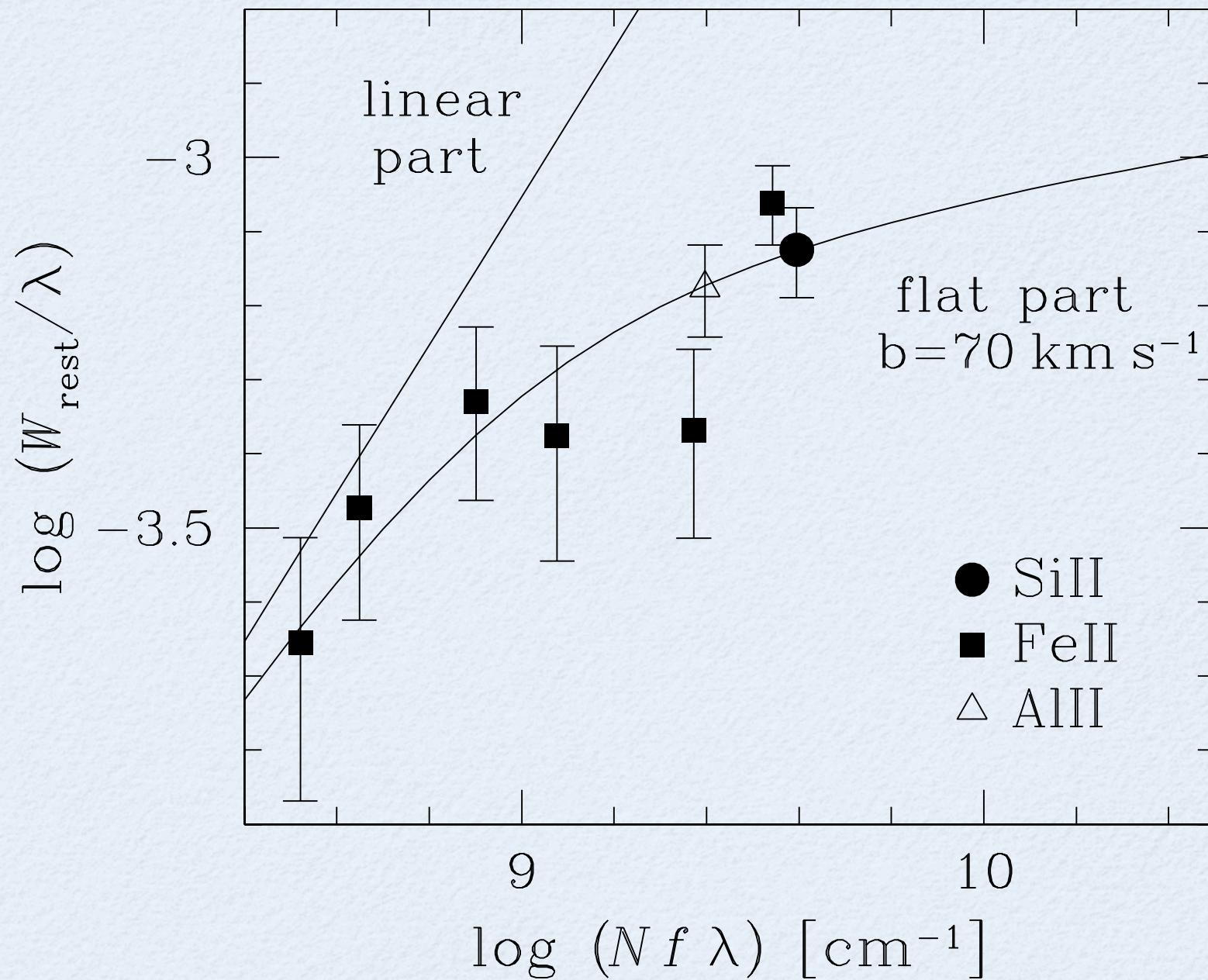
from thesis of Sara Ellison (2000)

CURVE OF GROWTH

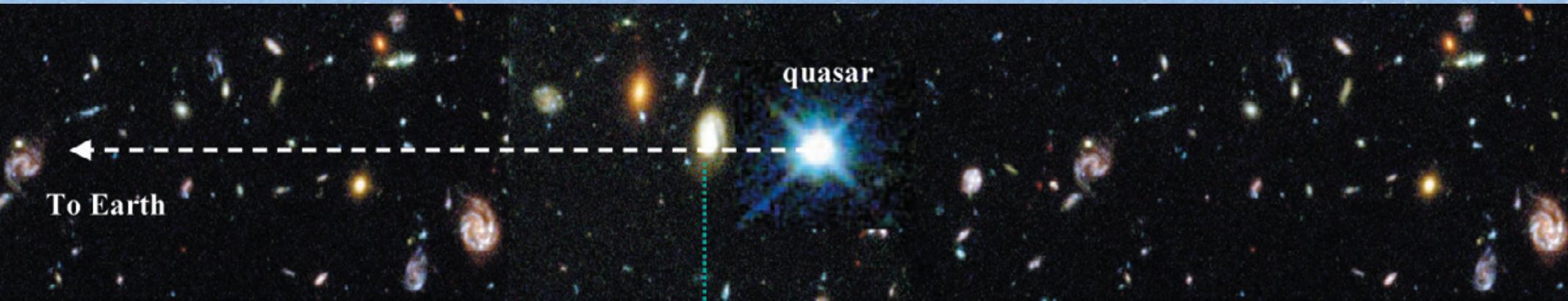
from thesis of Sara Ellison (2000)



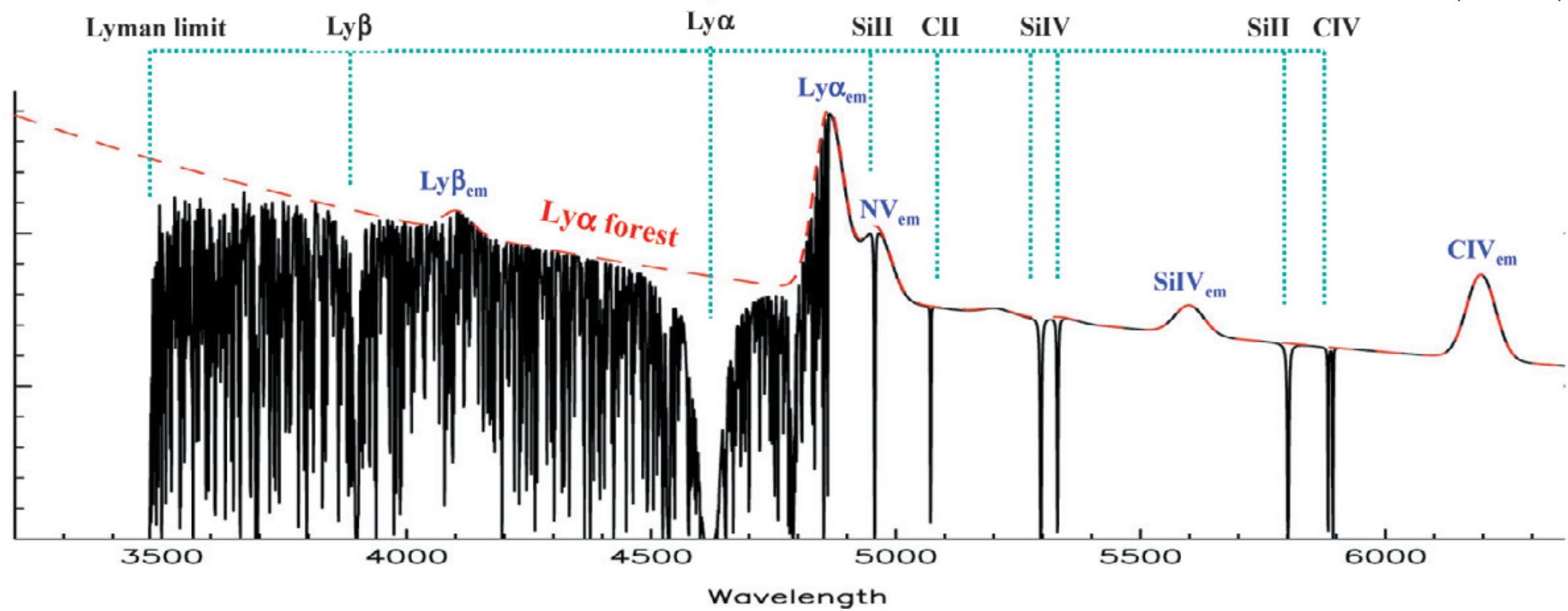
EXAMPLE: GRB011211



QSO ABSORBERS



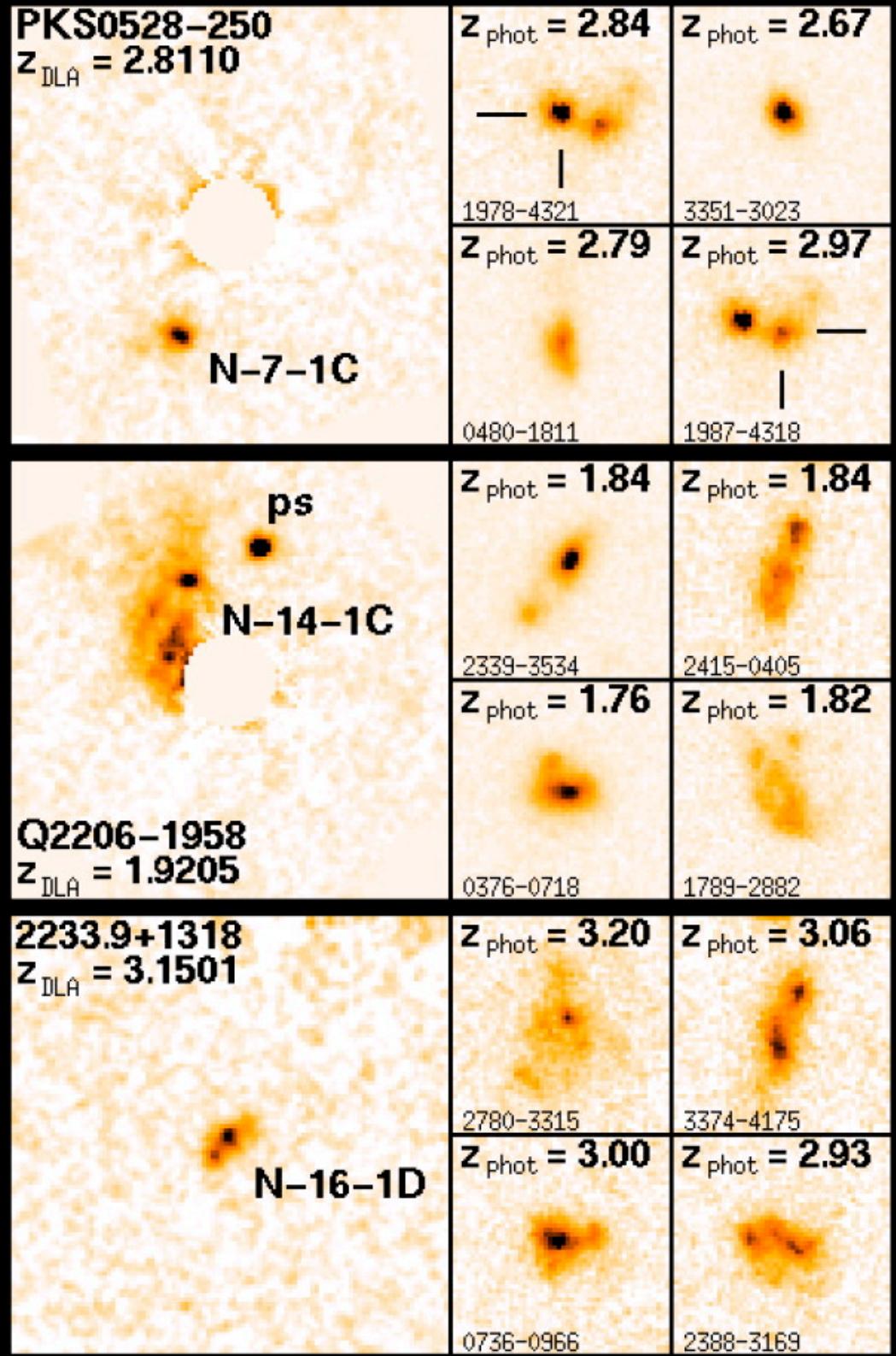
Pettini (2003)



QSO ABSORBERS

system type	log N(HI)	associated with	interest?
Ly α forest	$\gtrsim 12.0$	intergalactic medium	IGM abundances
MgII systems	$\gtrsim 17.2$	galaxy halos	halo sizes and abundances
DLas	$\gtrsim 20.3$	proto-galaxy	contain bulk of neutral gas

see thesis of Sara Ellison (2000)

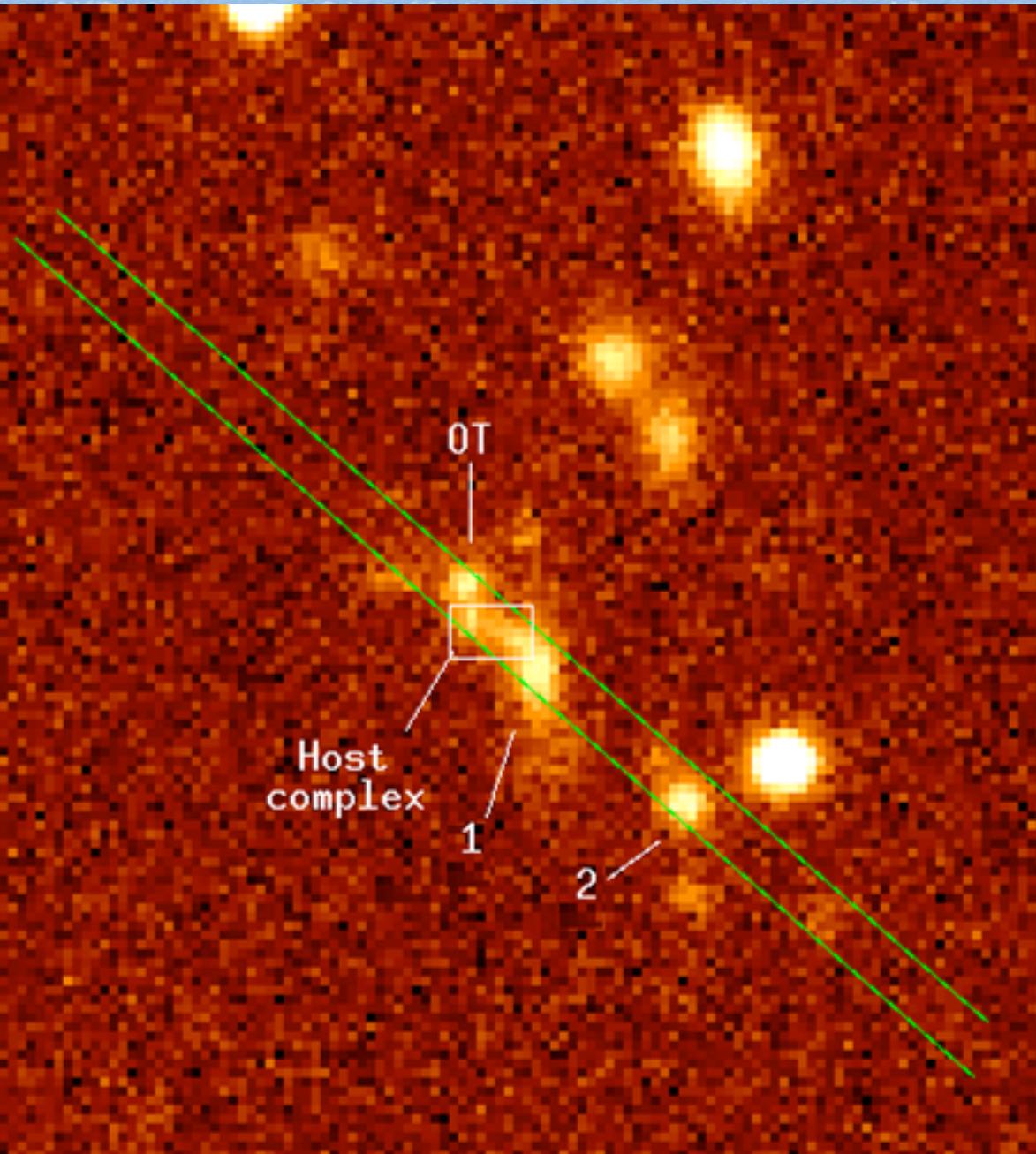


QSO EXAMPLE

- only handful of DLA counterparts known (more at low redshift)
- difficult due to bright QSO in background
- DLA galaxy properties similar to Lyman Break Galaxies (LBGs)

Møller et al. (2002)

GRB 020405 SIGHTLINE

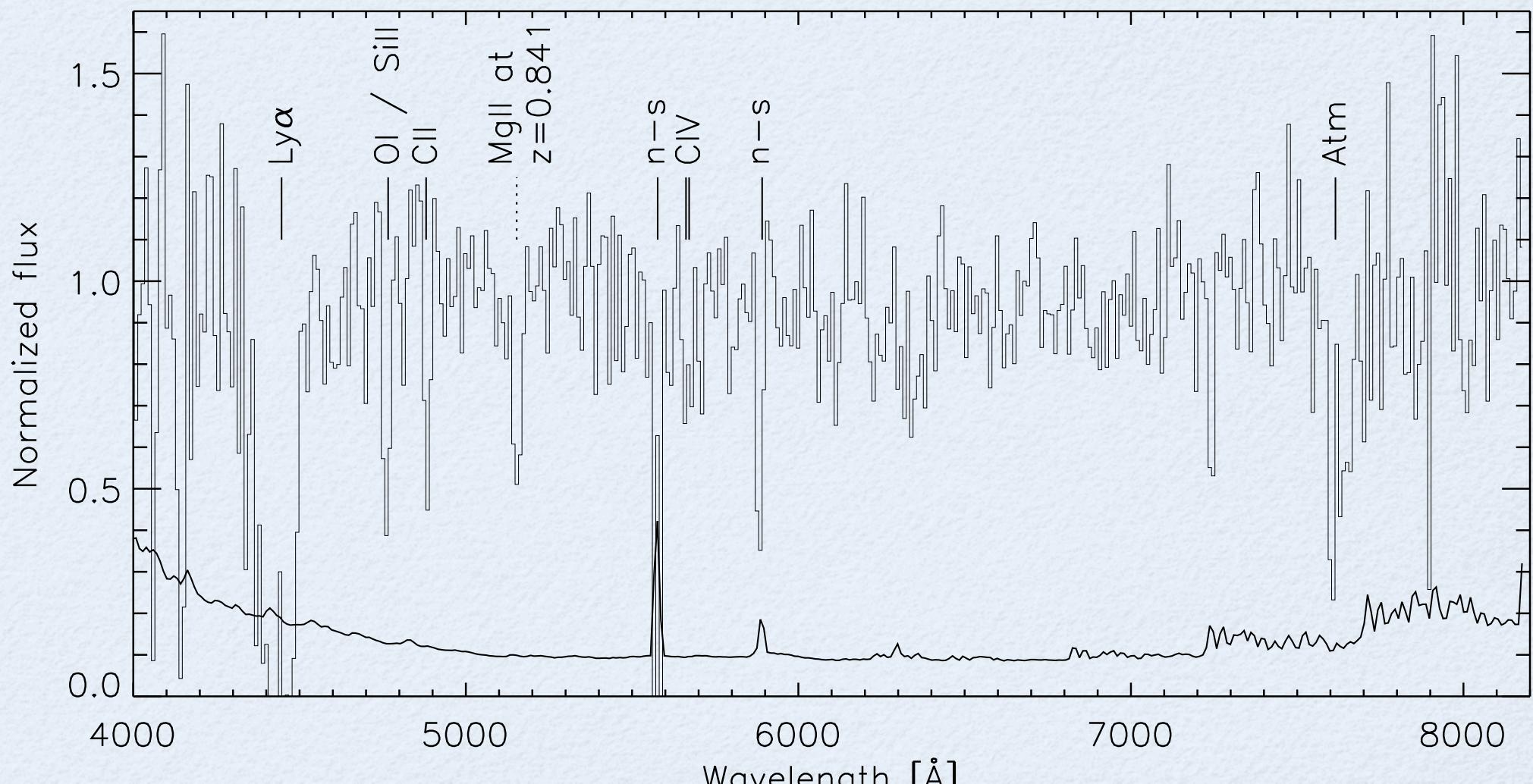


- GRB at $z=0.69$
- $z=0.47$ absorber
- 1+2 show $z=0.47$ emission lines
- OT-''1'' = 13 kpc

Masetti et al. (2003)

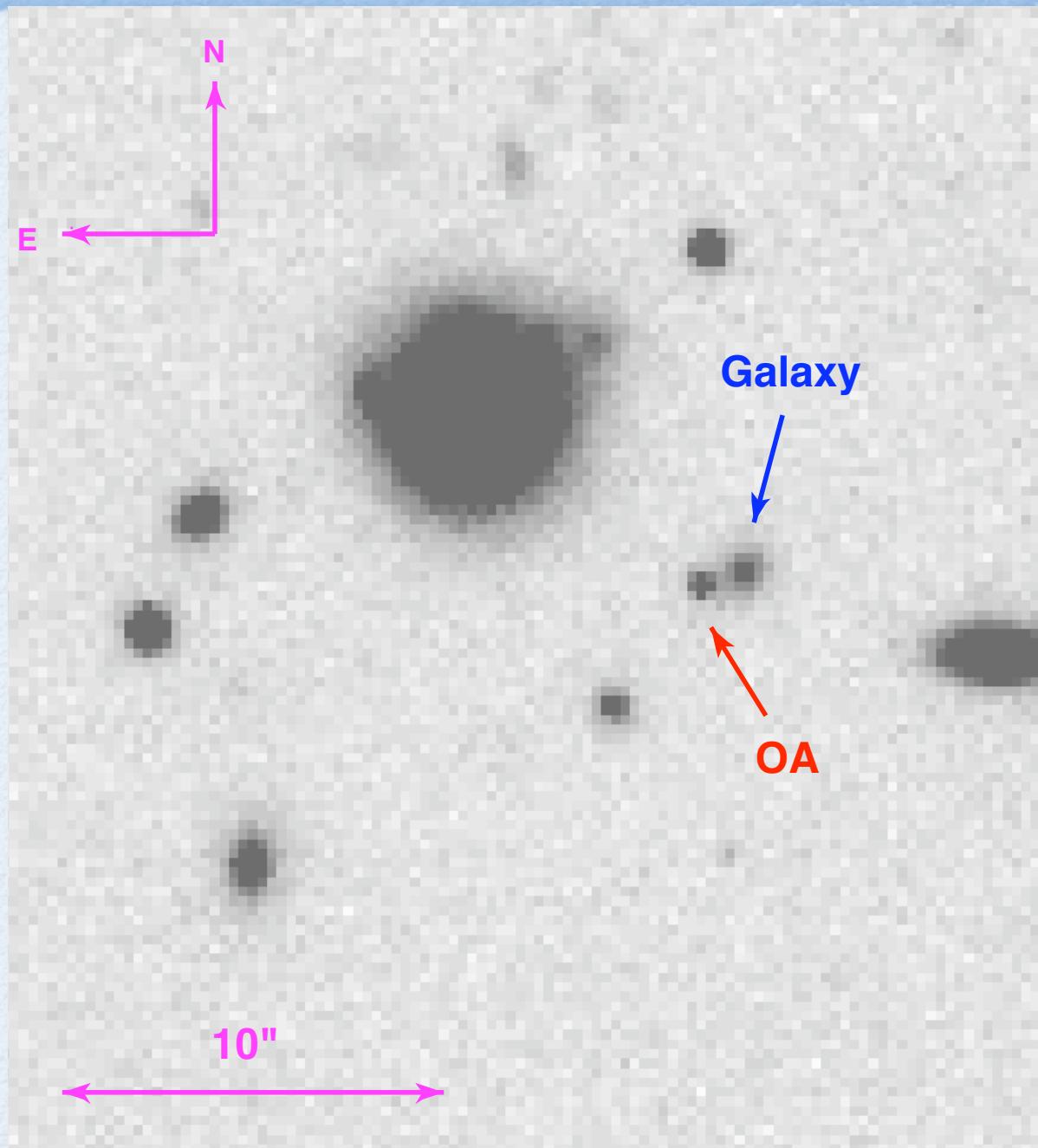
GRB 030429 SIGHTLINE

Jakobsson et al. (2004)



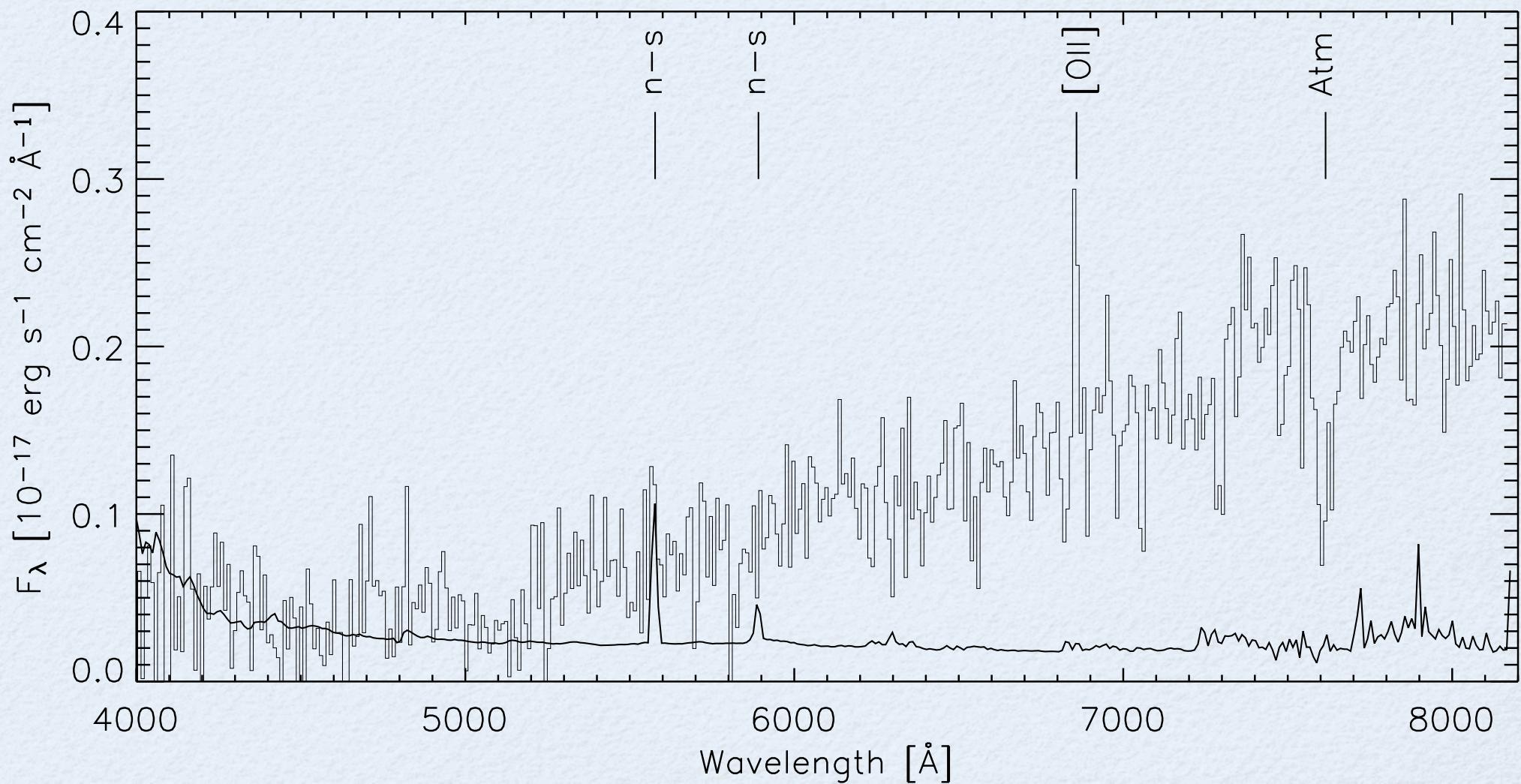
GRB 030429 SIGHTLINE

- GRB at $z=2.66$



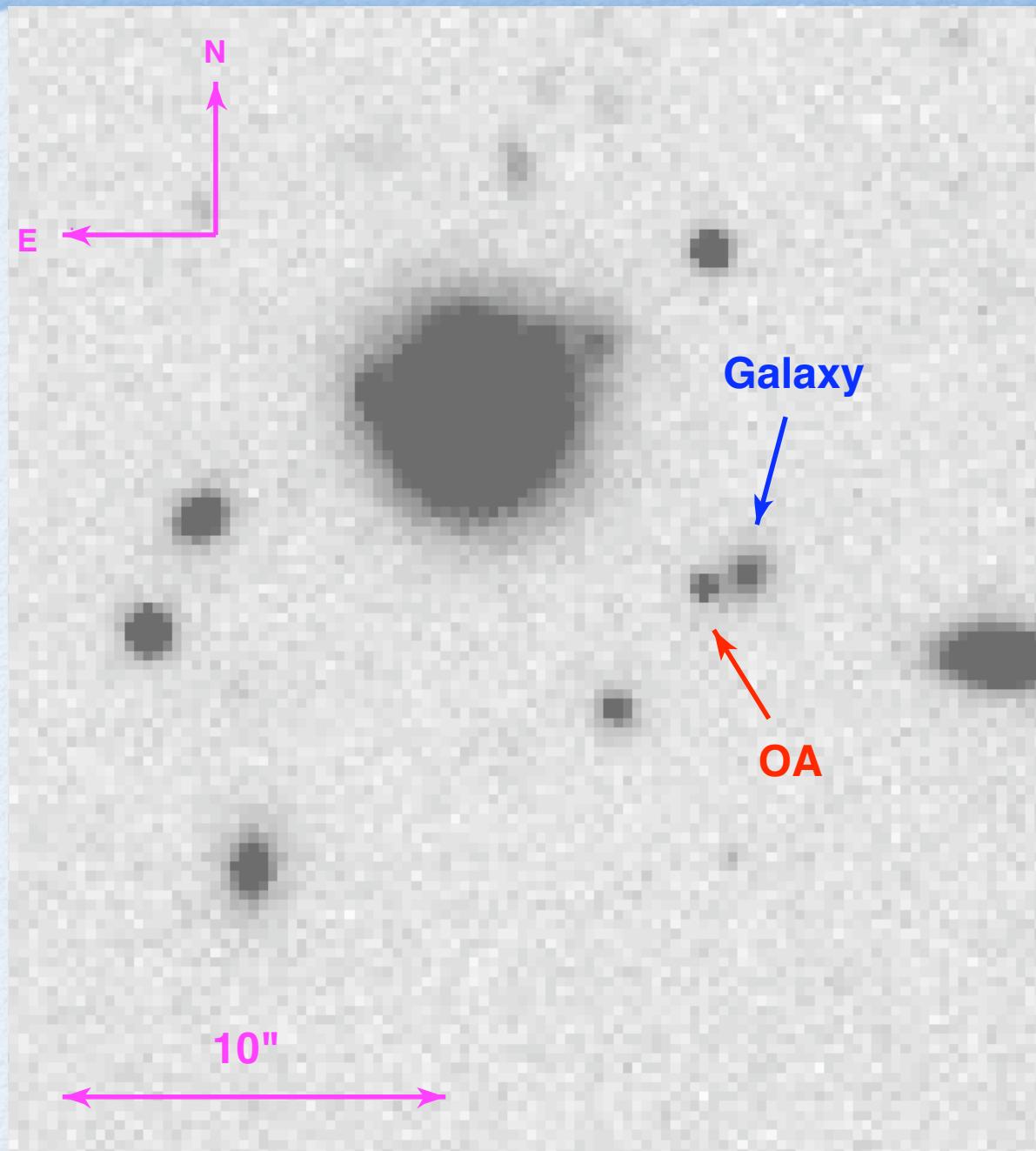
GRB 030429 SIGHTLINE

Jakobsson et al. (2004)



GRB 030429 SIGHTLINE

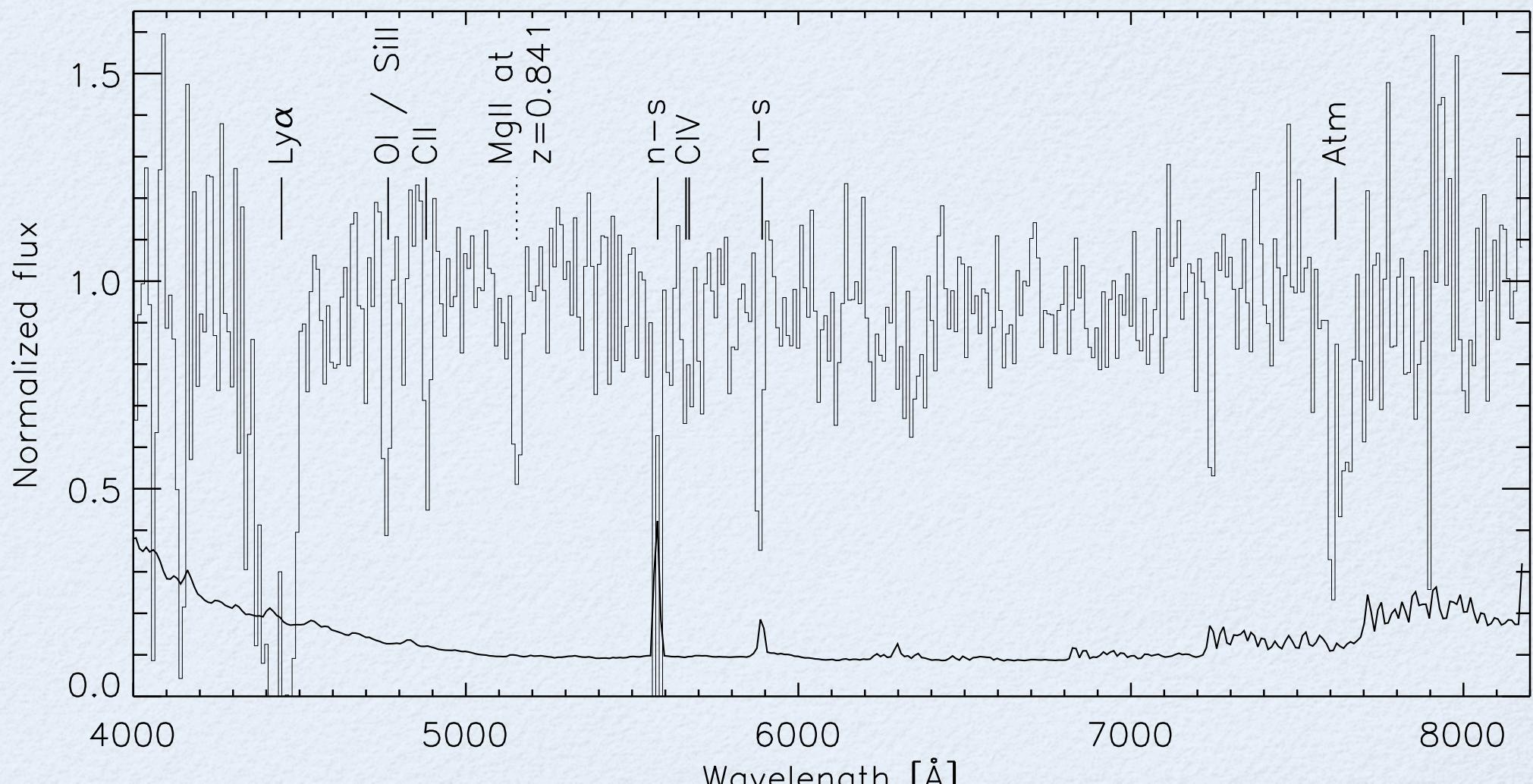
- GRB at $z=2.66$
- star-forming galaxy at $z=0.84$ is only 9kpc from OA sightline



Jakobsson et al. (2004)

GRB 030429 SIGHTLINE

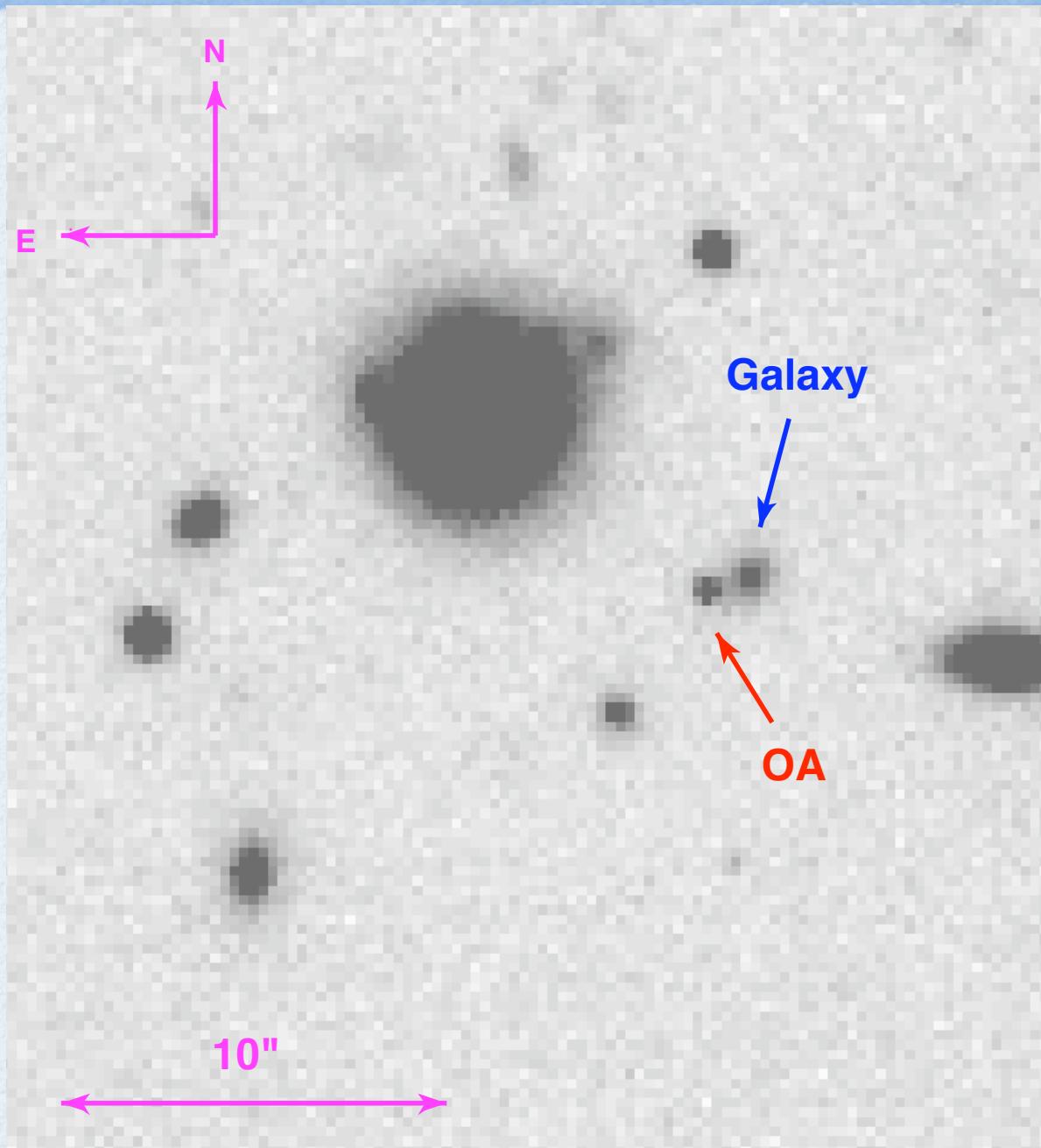
Jakobsson et al. (2004)



GRB 030429 SIGHTLINE

- GRB at $z=2.66$
- star-forming galaxy at $z=0.84$ is only 9kpc from OA sightline
- SED fitting: $A(V)=0.8$ and young (0.5-1Gyr) population of stars

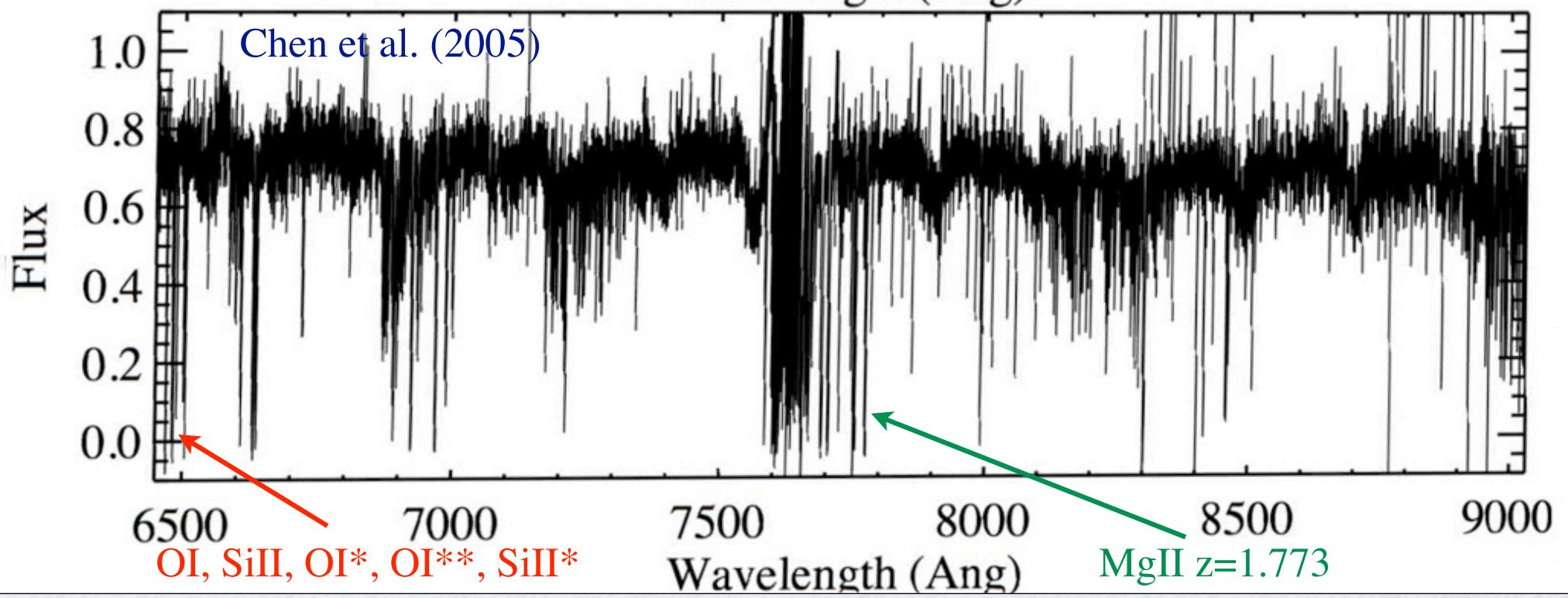
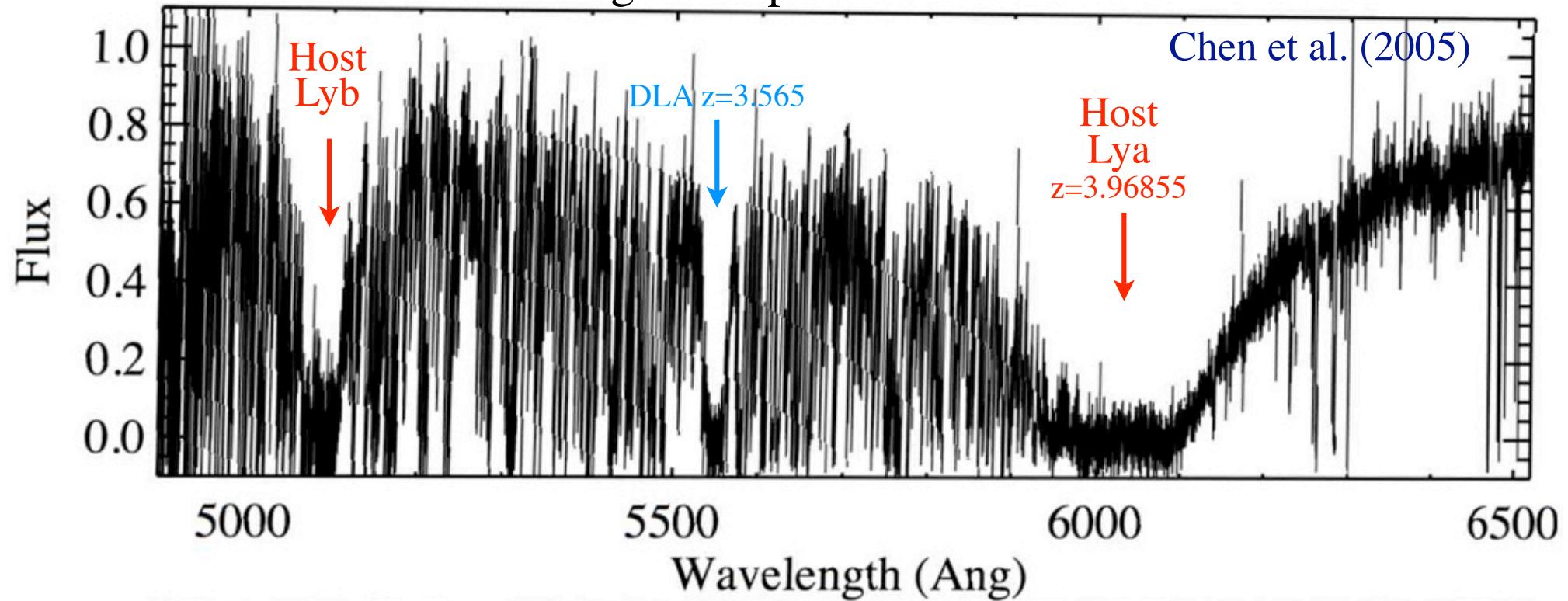
Jakobsson et al. (2004)



FOREGROUND ABSORBERS

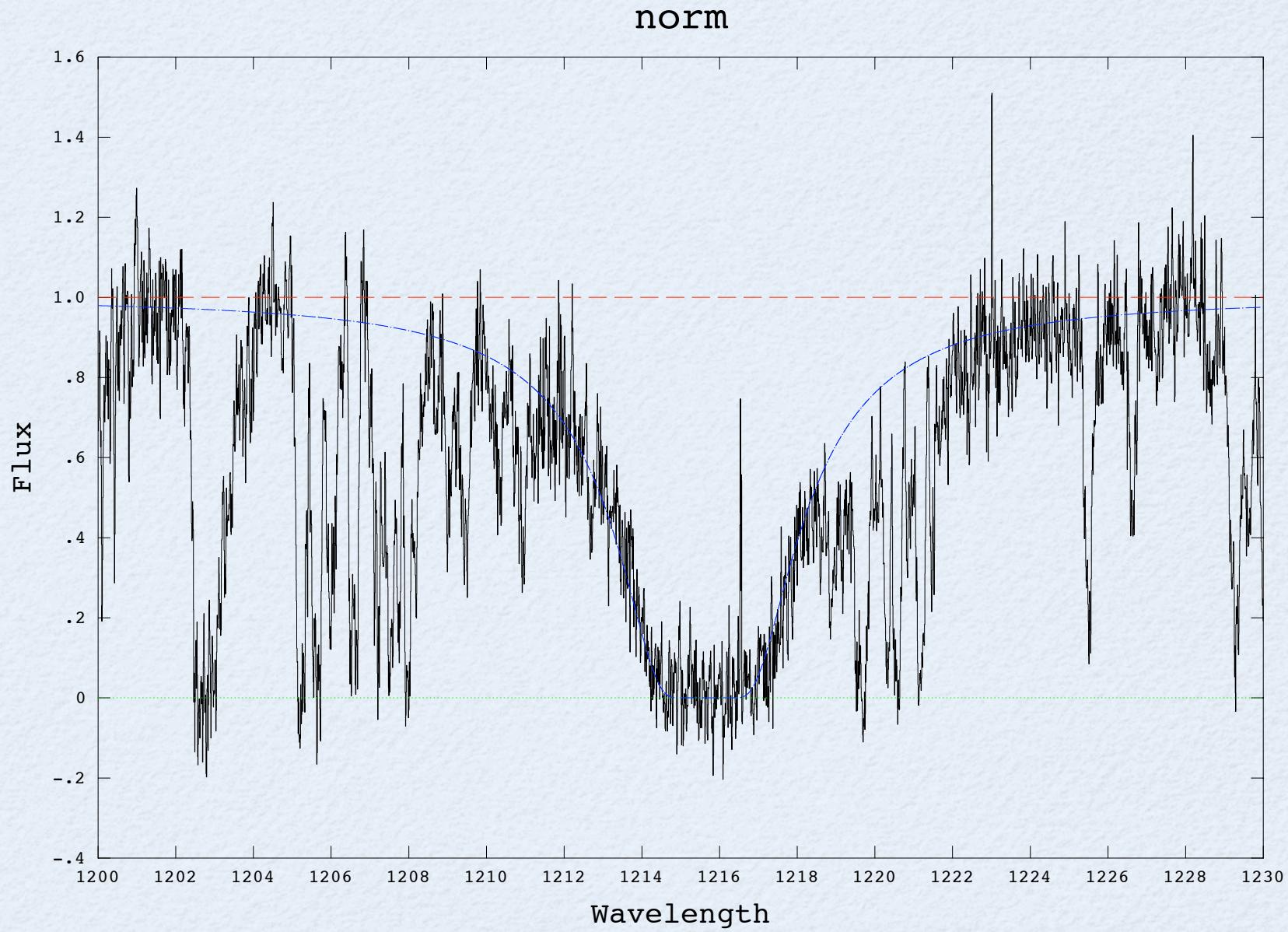
- 2 confirmed GRB MgII absorbers at $z=0.7-0.8$ with ~ 10 kpc impact parameters
- QSO MgII absorbers (two dozen) at $0.3 < z < 1.3$ are at 12-127 kpc (Guillemin & Bergeron et al. 1997)

MIKE/Magellan Spectrum of GRB 050730



ABSORBER IN GRB050820

foreground sub-DLA with $\log N(\text{HI}) = 20.0$ at $z=2.36$



GRB VS QSO ABSORBERS

- GRB afterglow disappears, while QSO sticks around
- so hard to take a spectrum with the same quality as QSO spectra, but allows late-time deep imaging
- very recent progress thanks to Swift: foreground DLA and sub-DLA found in GRB sightlines 050730 and 050820

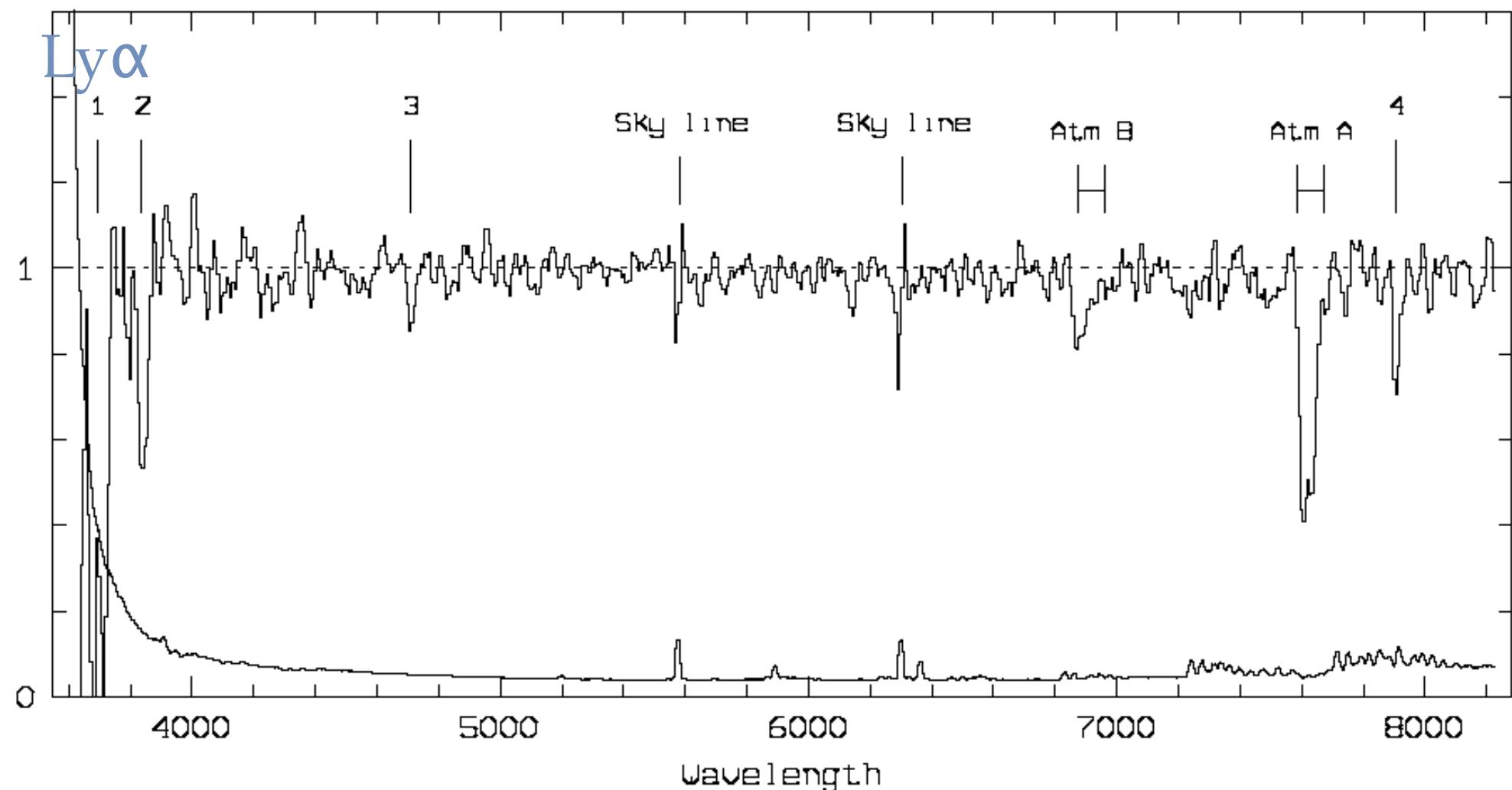
GRB HOST-GALAXY DLAs

- difference with QSO host galaxies: GRB does not disturb host galaxy beyond tens of parsecs
---> probe ISM of GRB hosts up to high redshift
- long GRBs come from massive stars ---> probe physical conditions in massive-star forming regions

GRB000301C DLA @ $Z=2.03$

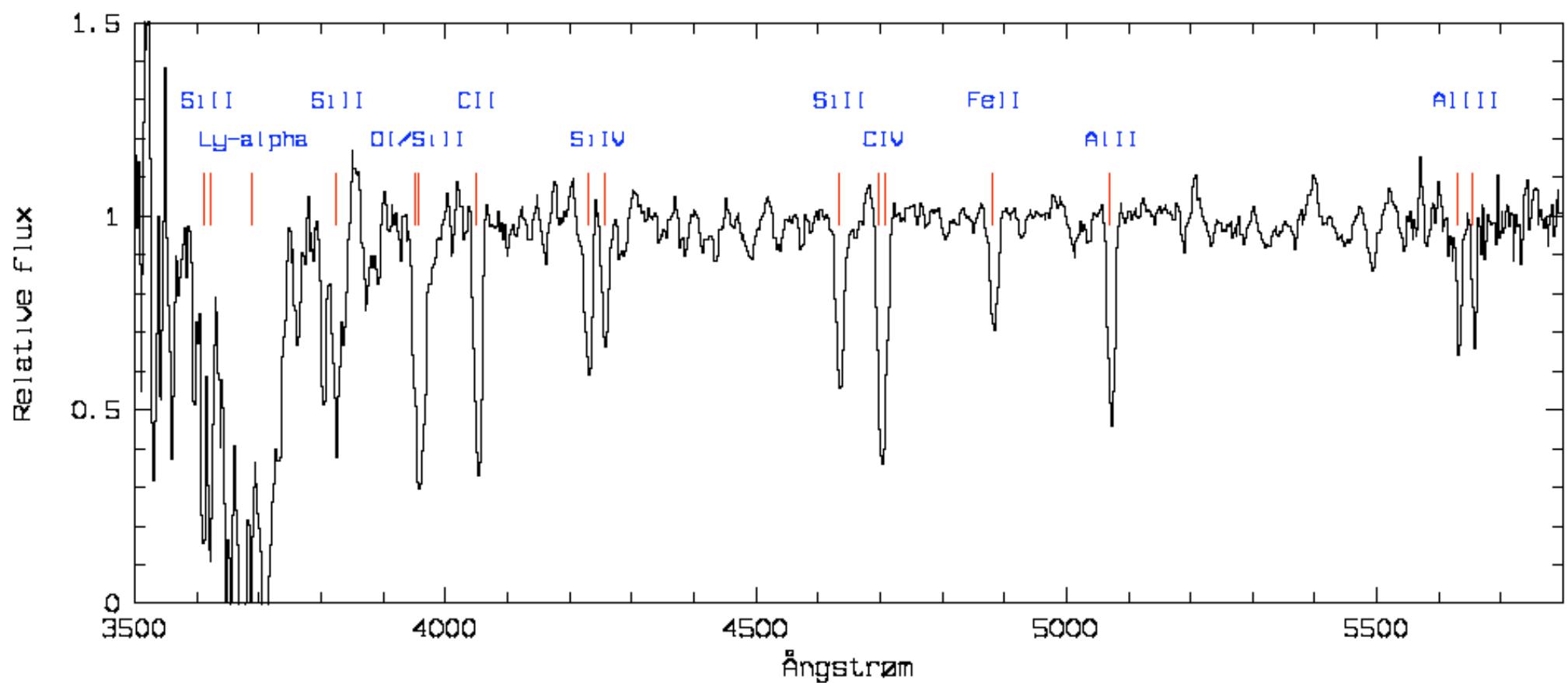
first reported GRB DLA

Jensen, Fynbo, Gorosabel et al. (2001)

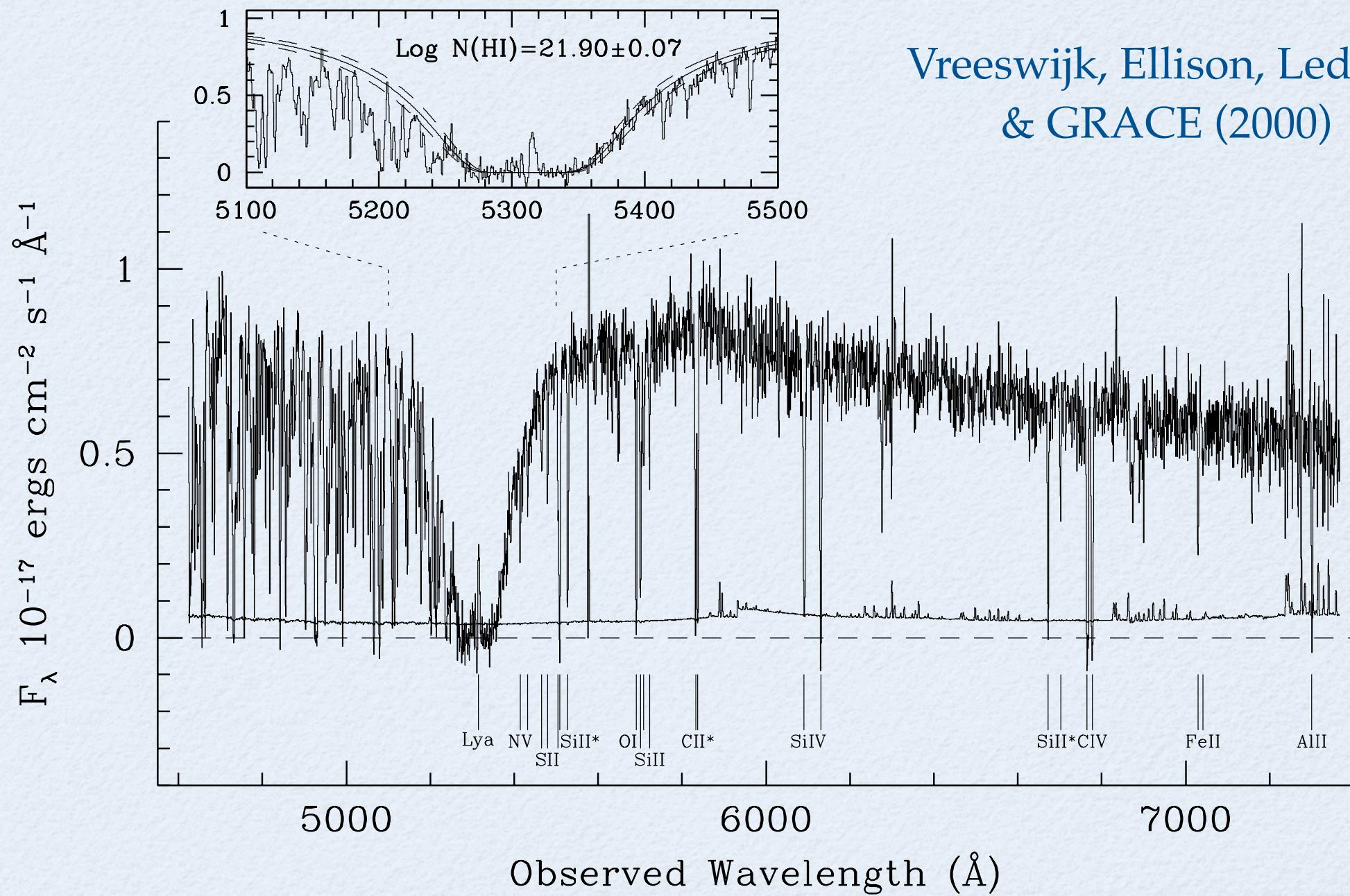


GRB000926 DLA @ Z=2.037

Fynbo, Gorosabel, Møller et al. (2001)



GRB030323 DLA @ Z=3.37

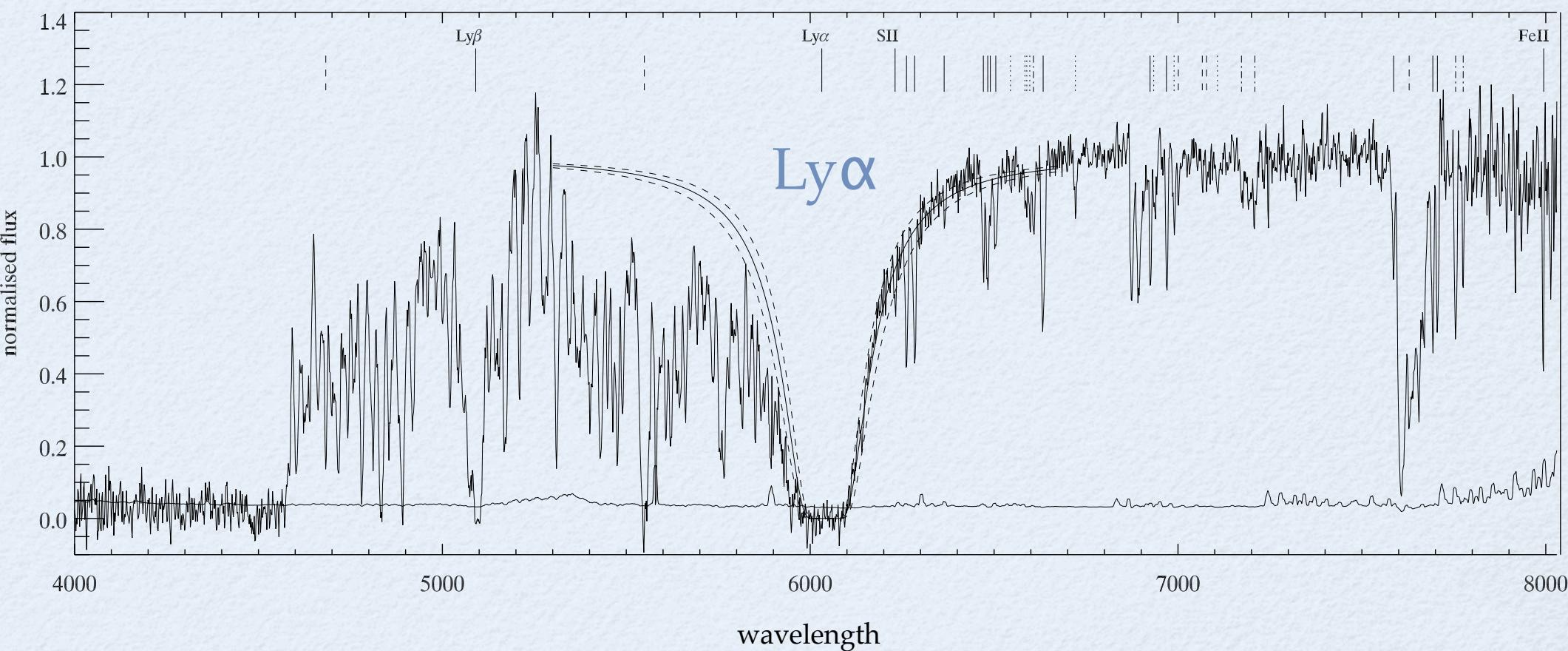


Vreeswijk, Ellison, Ledoux
& GRACE (2000)

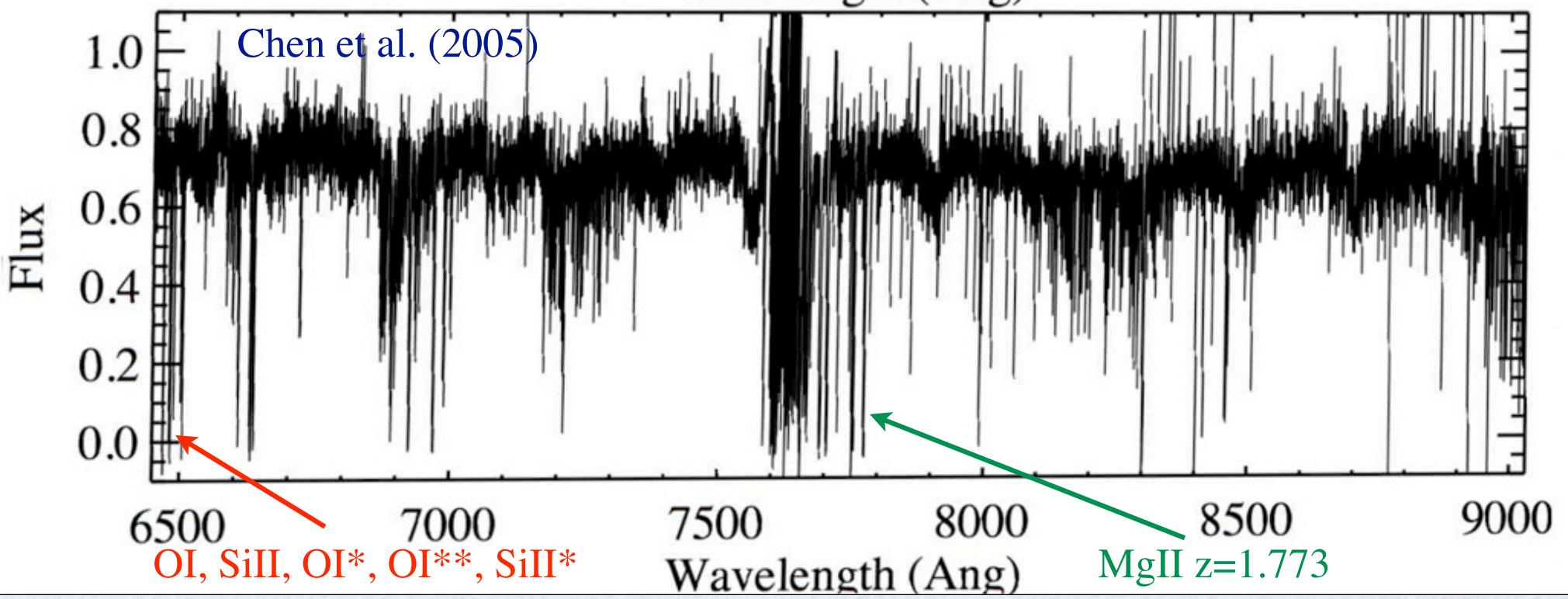
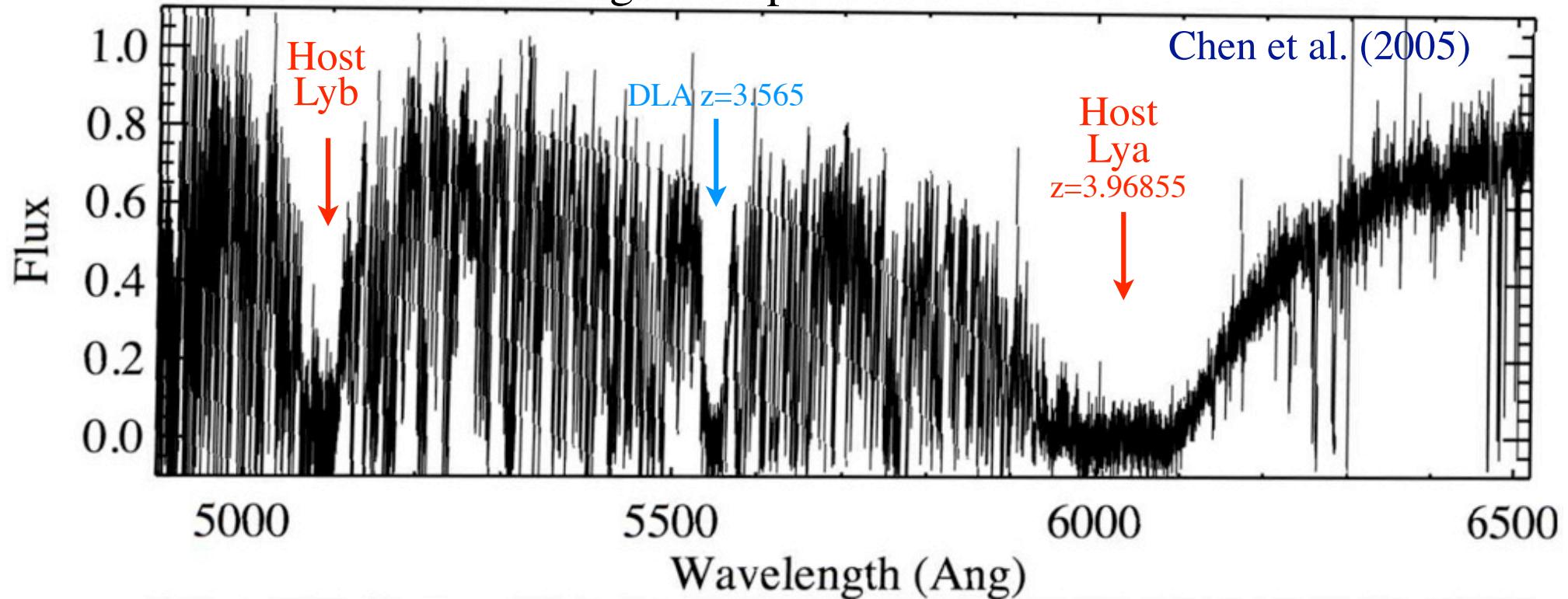
GRB050730 DLA @ Z=3.97

WHT spectrum

Starling, Vreeswijk, Ellison, Rol et al. (2005)

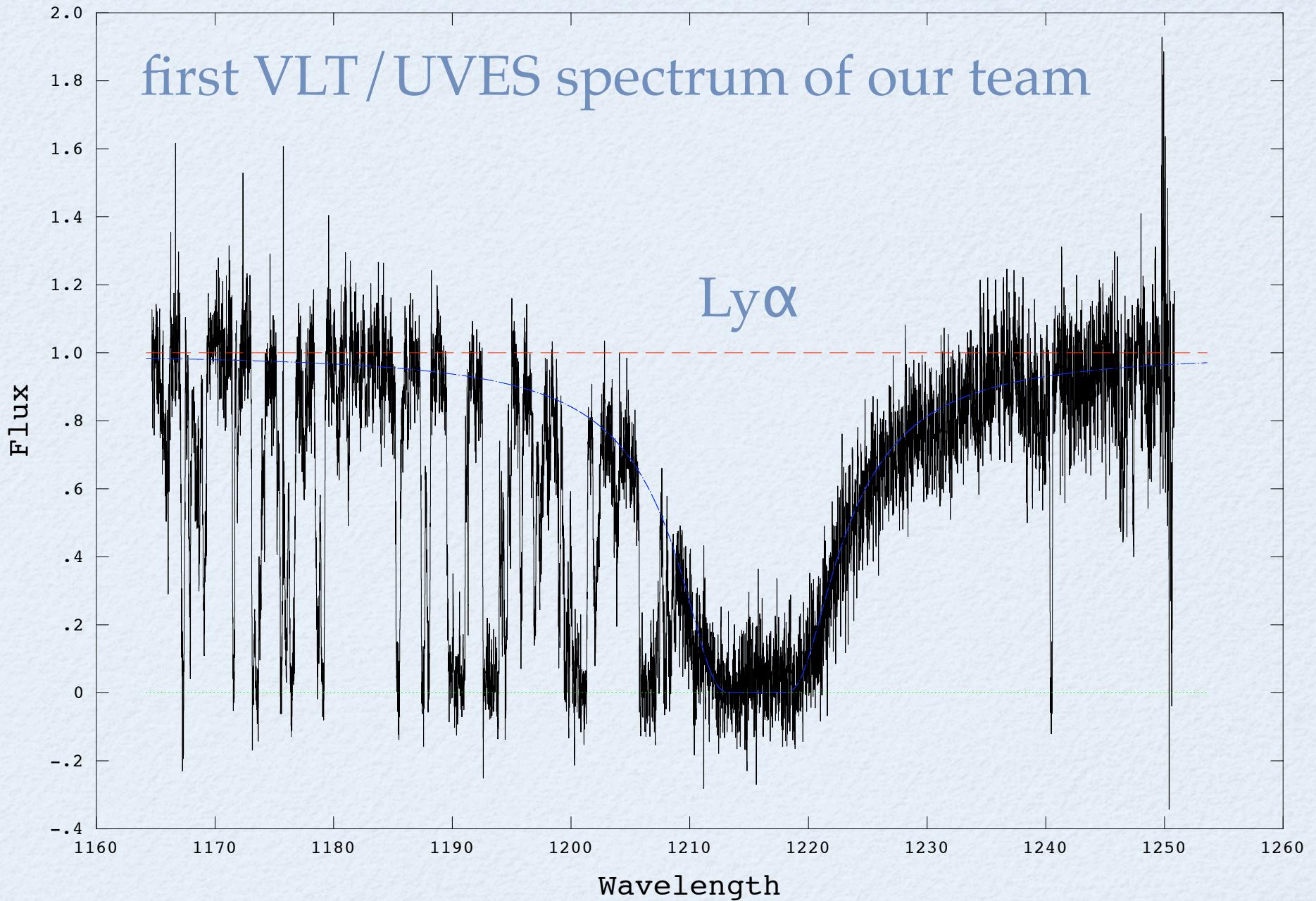


MIKE/Magellan Spectrum of GRB 050730



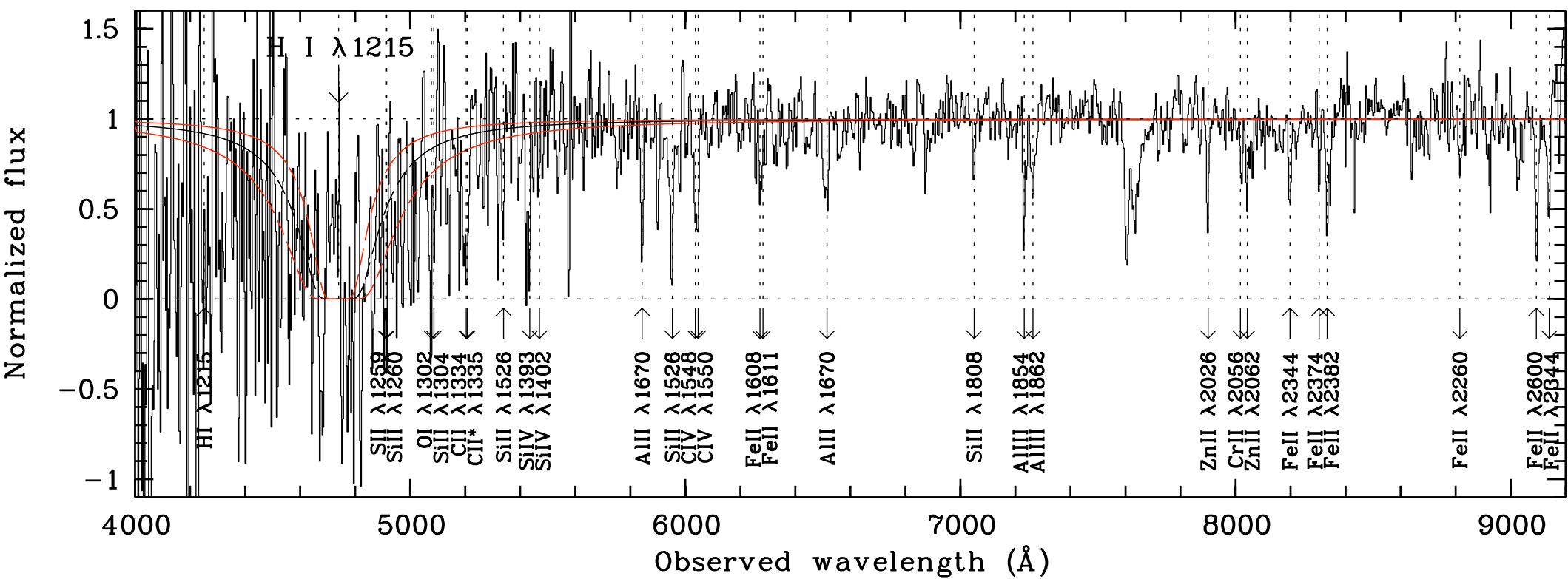
GRB050820 DLA @ Z=2.615

norm

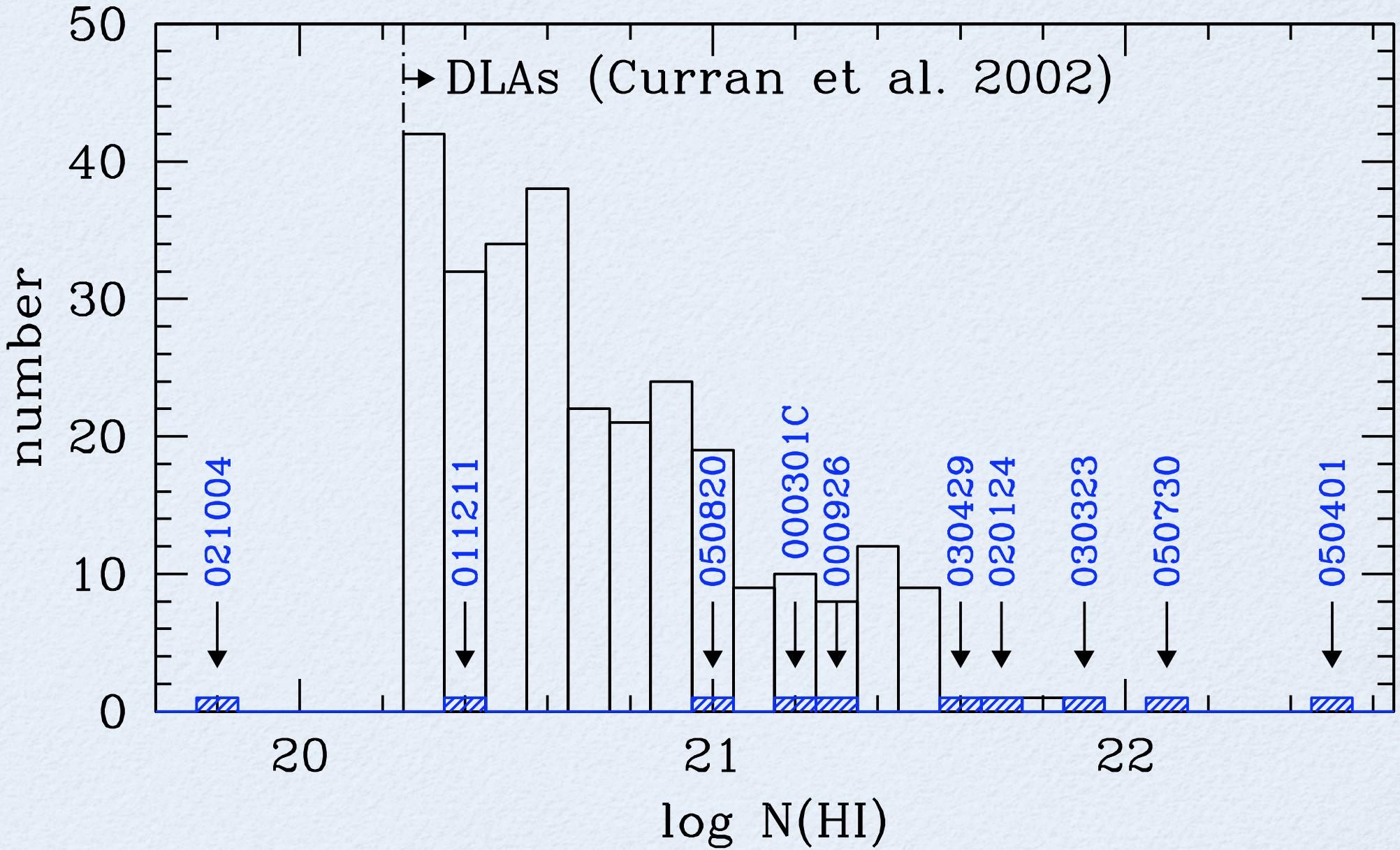


GRB050401 DLA @ Z=2.9

Watson, Fynbo, Ledoux et al. (2005)



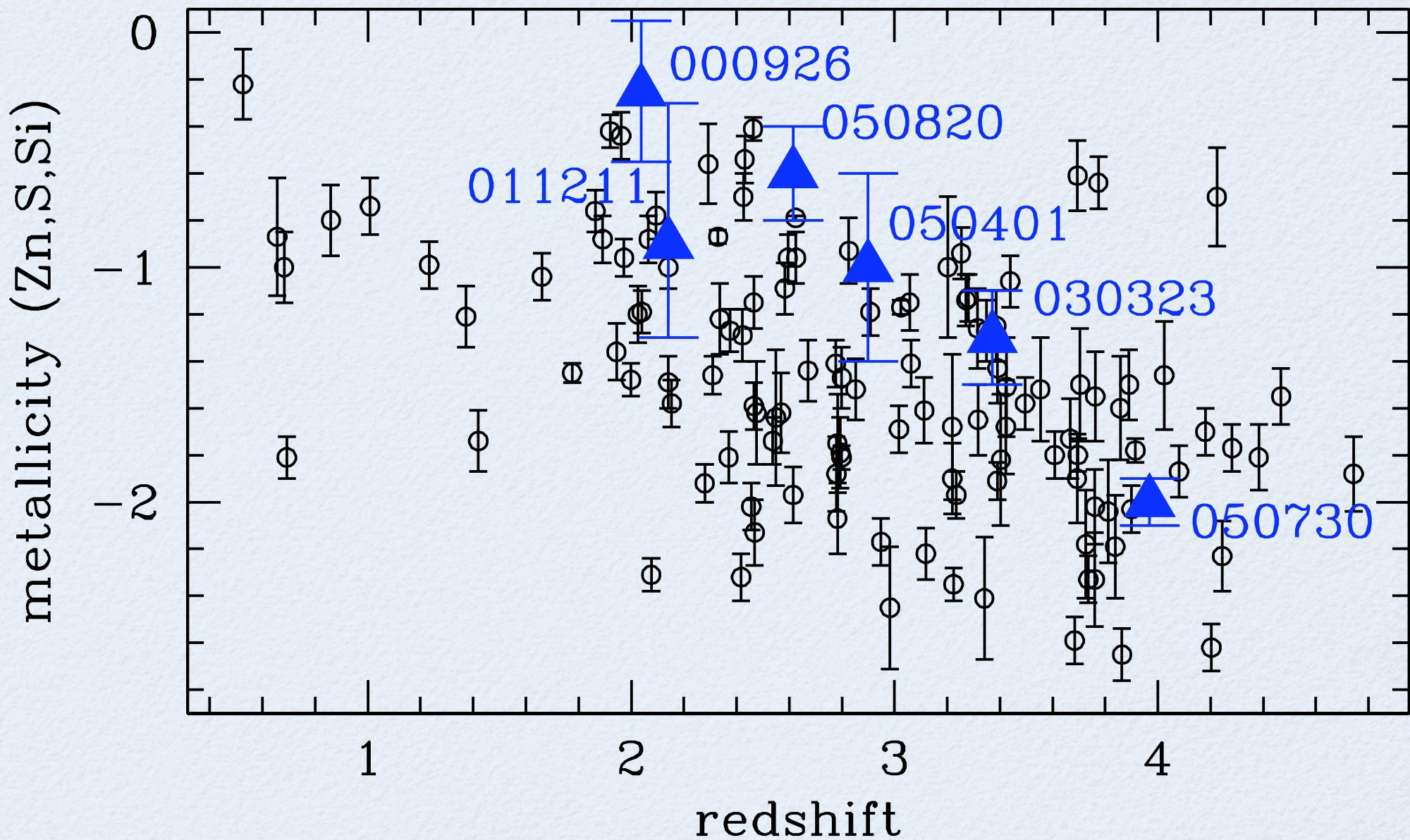
DLAS IN QSOs AND GRBS



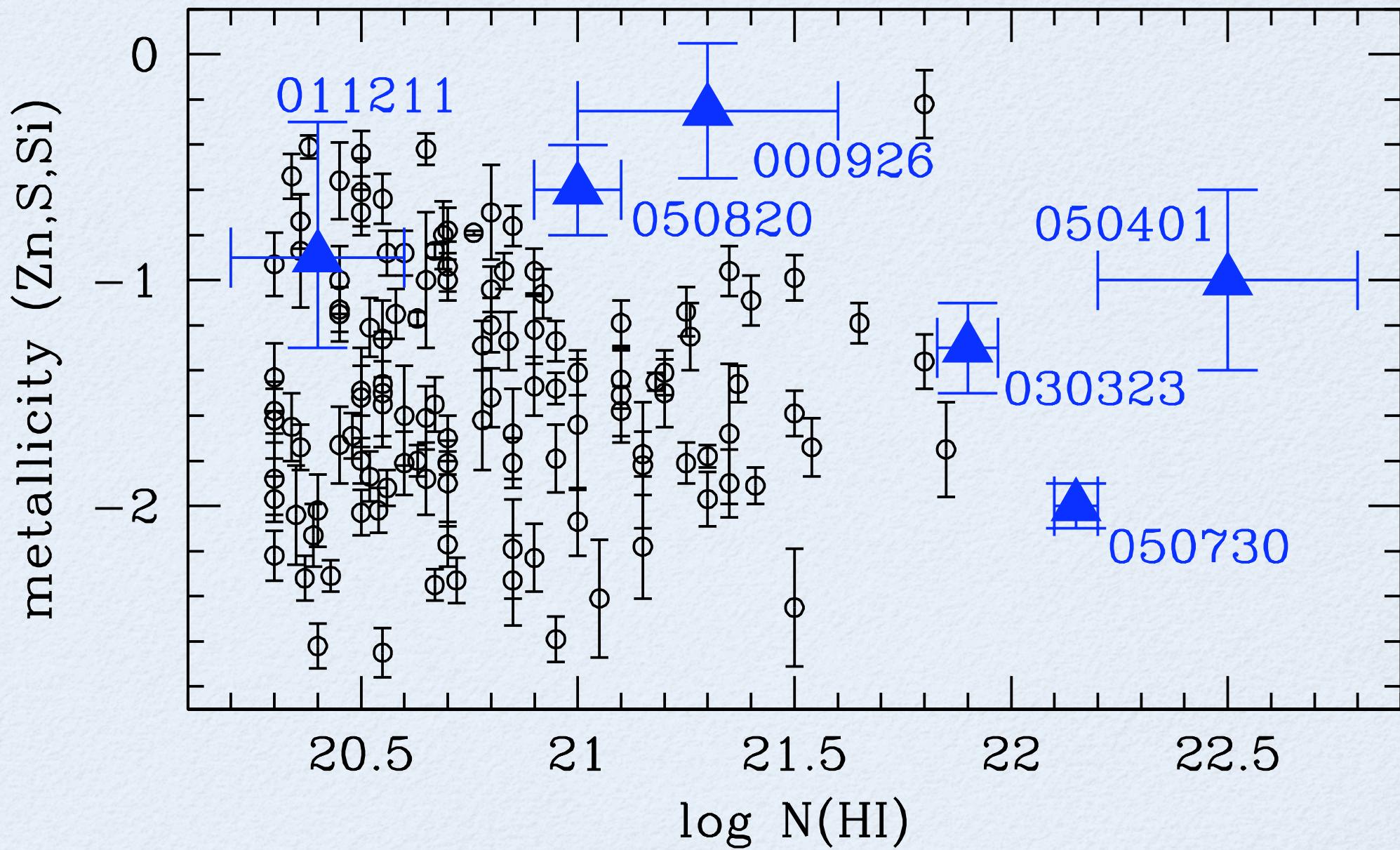
METALLICITY

- measure columns from line fitting, EW measurement, or curve-of-growth
- $[X/H] = \log \{N(X)/N(HI)\} - \log \{N(X)/N(HI)\}_\odot$.
- assume that X is dominant ionization stage of that particular element

DLA METALLICITIES



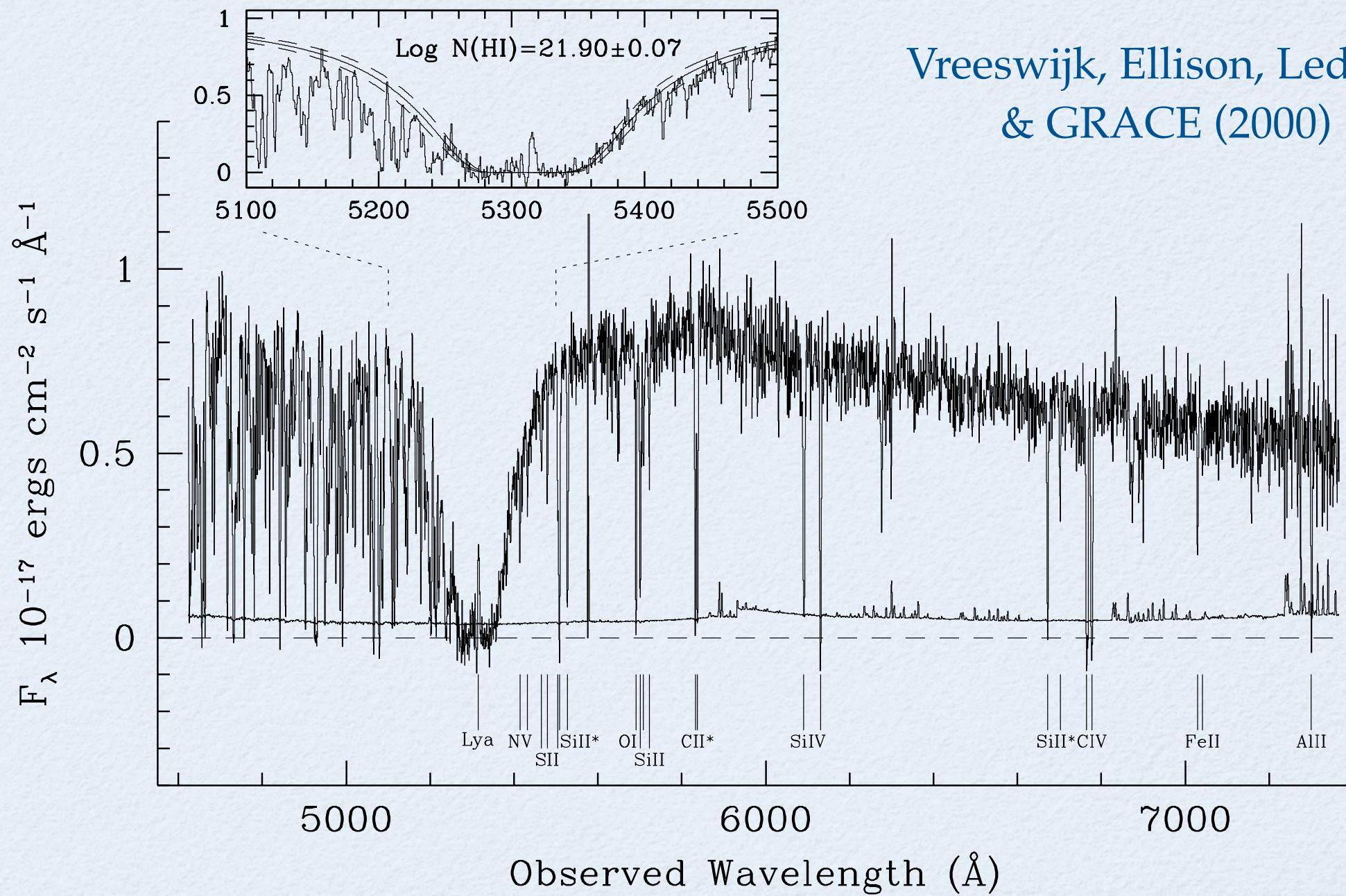
DLA METALLICITIES



FINE-STRUCTURE LINES

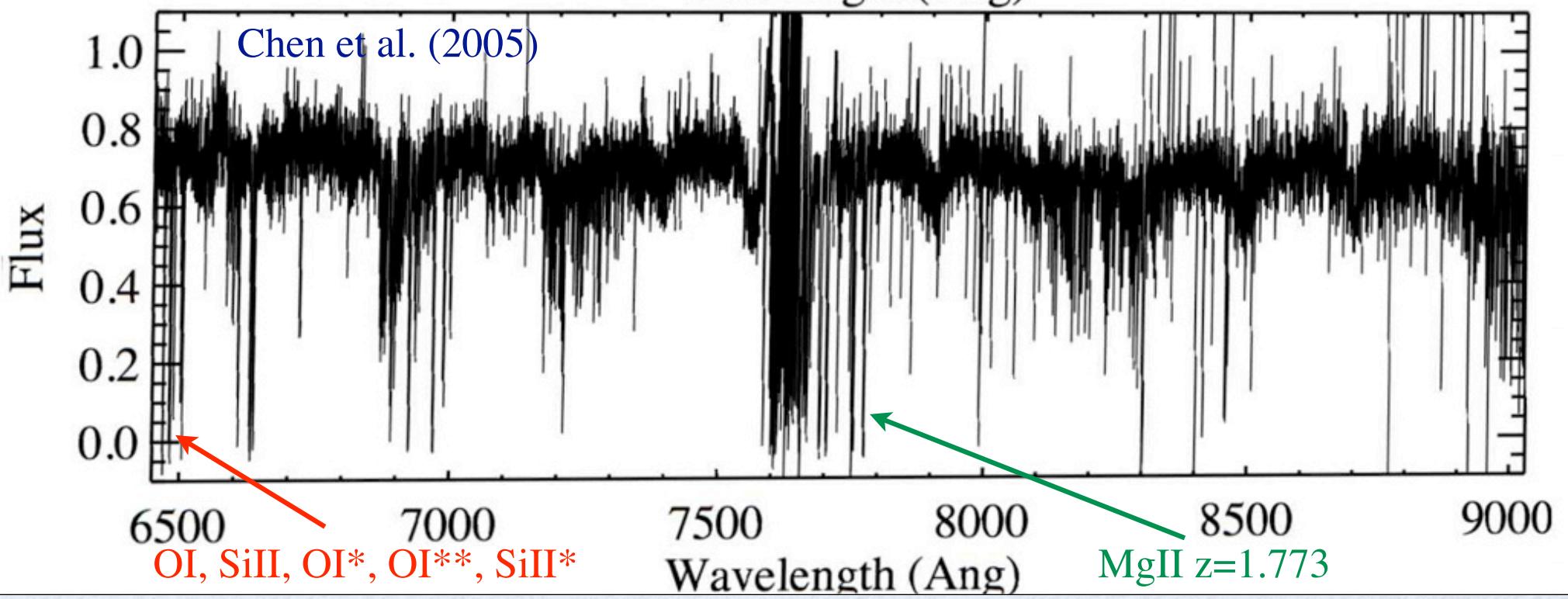
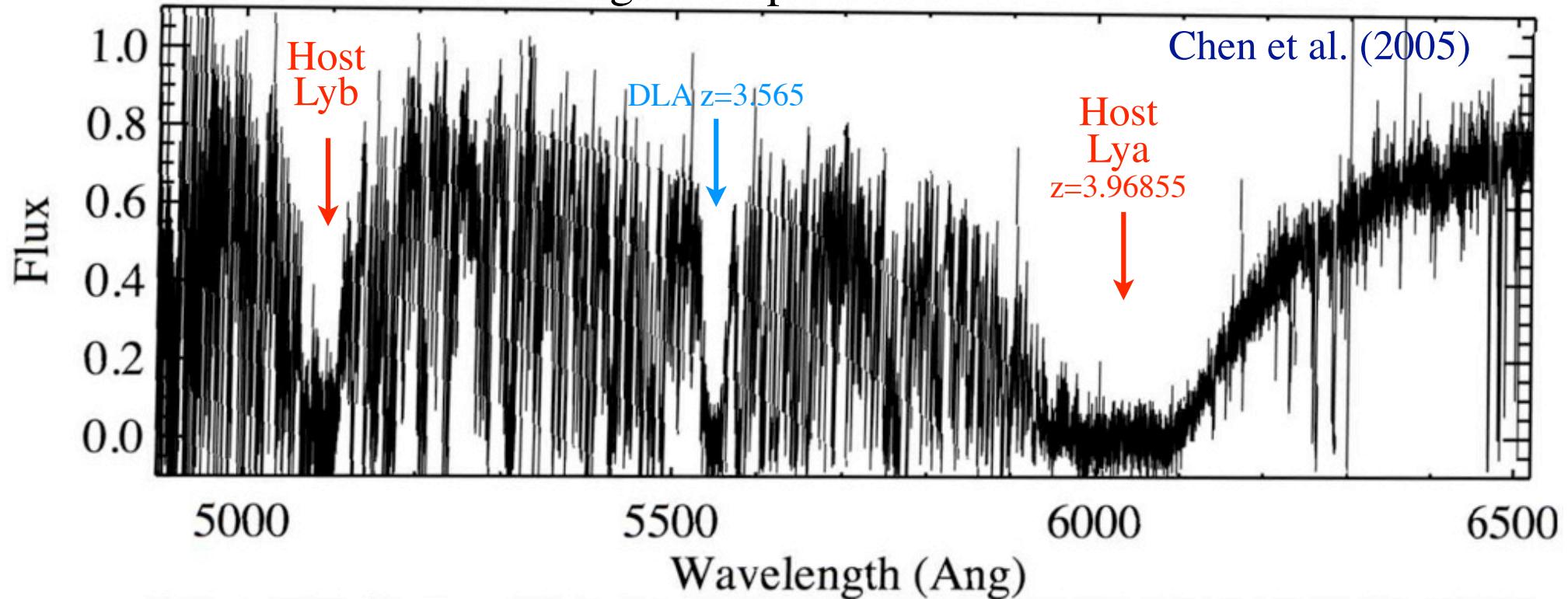
- energy level split due to interaction between total spin and orbital momentum of electrons
- CII*, SiII*, OI*, OII*, FeII* detected in GRB hosts

SILICON II* IN GRB030323



Vreeswijk, Ellison, Ledoux
& GRACE (2000)

MIKE/Magellan Spectrum of GRB 050730



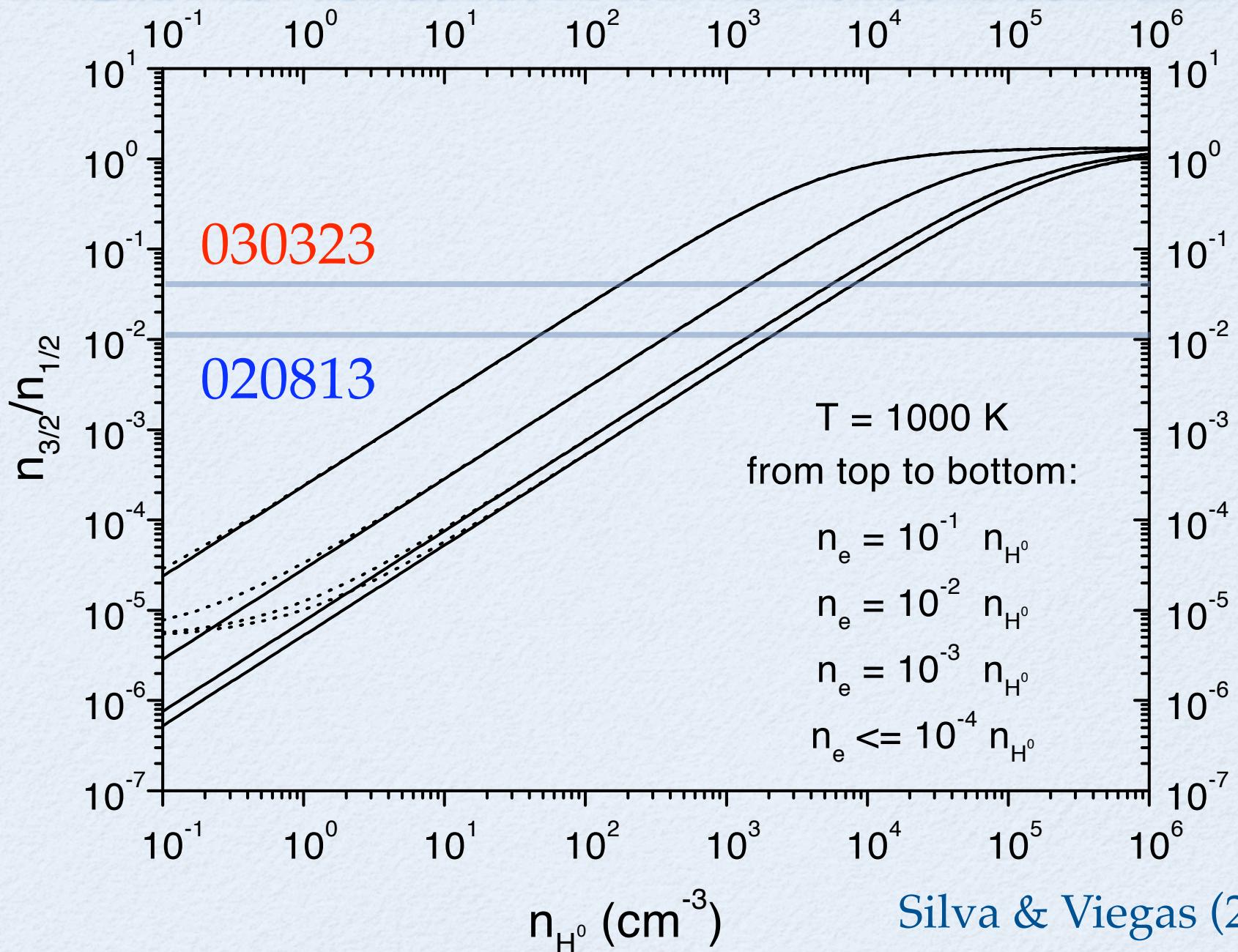
FINE-STRUCTURE LINES

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- except for CII*, never clearly detected in QSO-DLAs ---> suggestive of origin related to GRB

FINE-STRUCTURE LINES

- energy level split due to interaction between total spin and orbital momentum of electrons
- CII*, SiII*, OI*, OII*, FeII* detected in GRB hosts
- except for CII*, never clearly detected in QSO-DLAs ---> suggestive of origin related to GRB
- populated through particle collisions (density) or excitation by infra-red photons (ambient flux), or fluorescence

FINE-STRUCTURE LINES

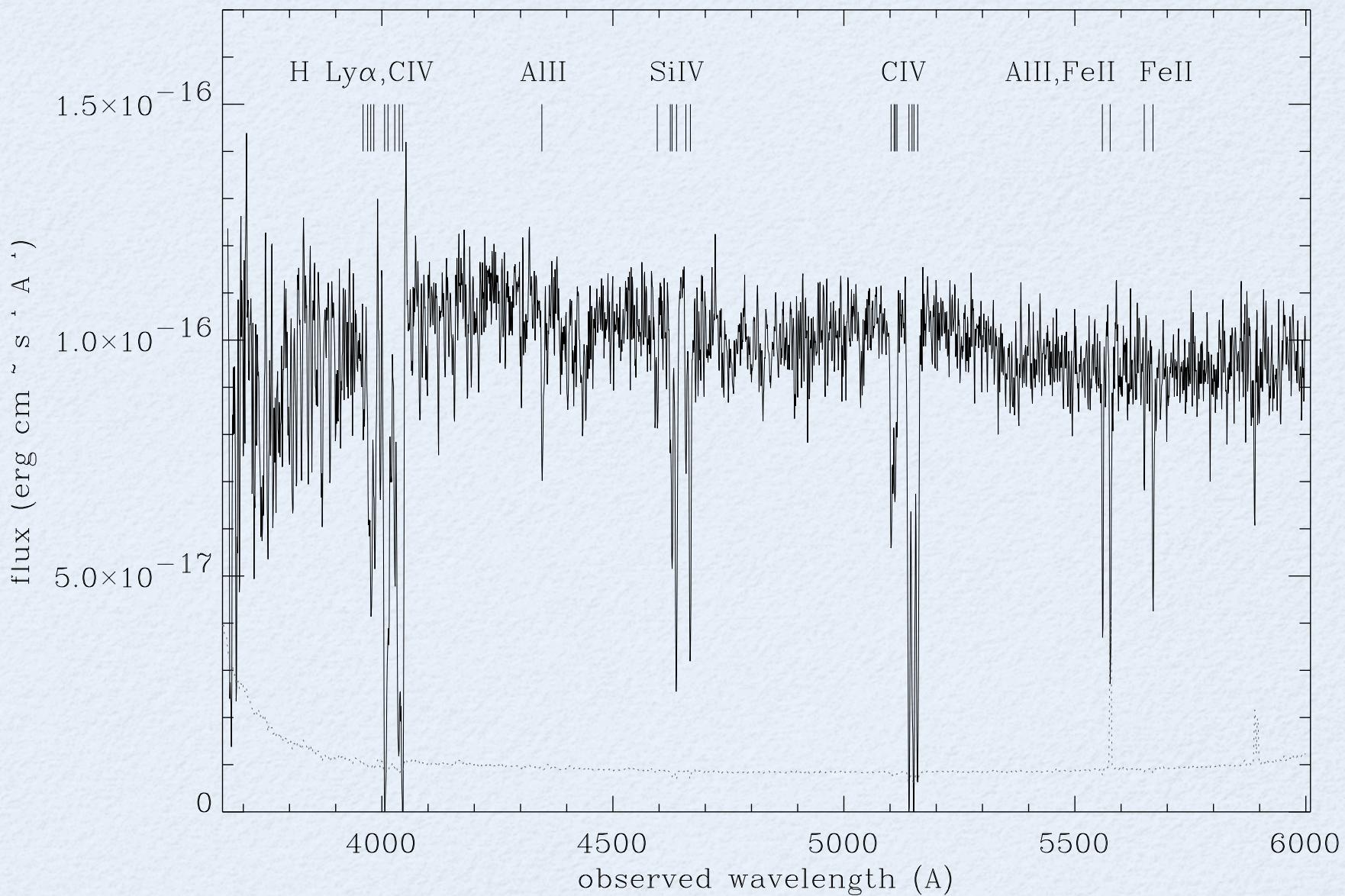


OUTFLOWS IN GRB 021004

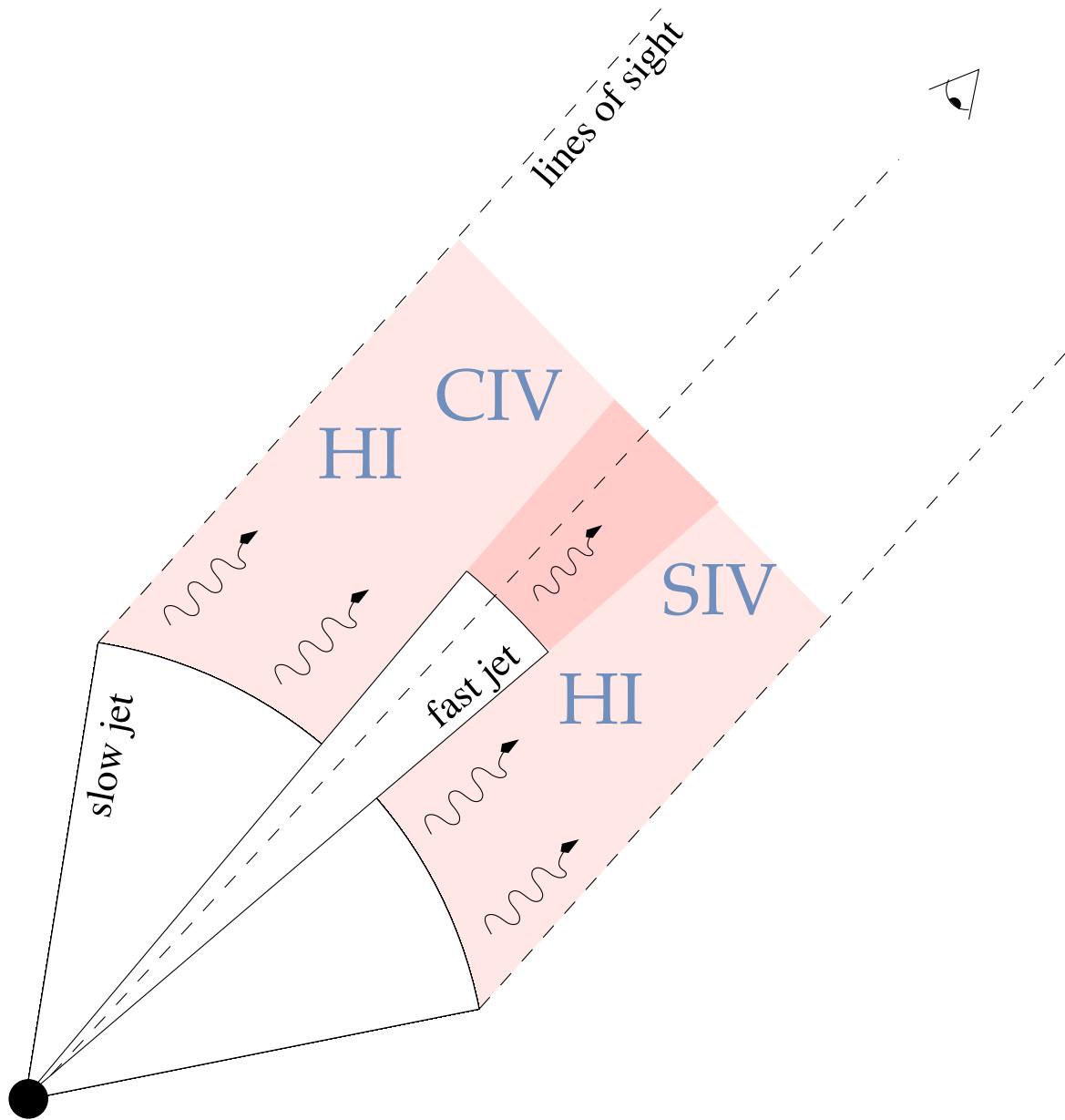
- absorption components with blueshifts up to ~3000 km/s (Schaefer et al., Mirabal et al., Møller et al., Starling et al., Fiore et al.)

GRB021004

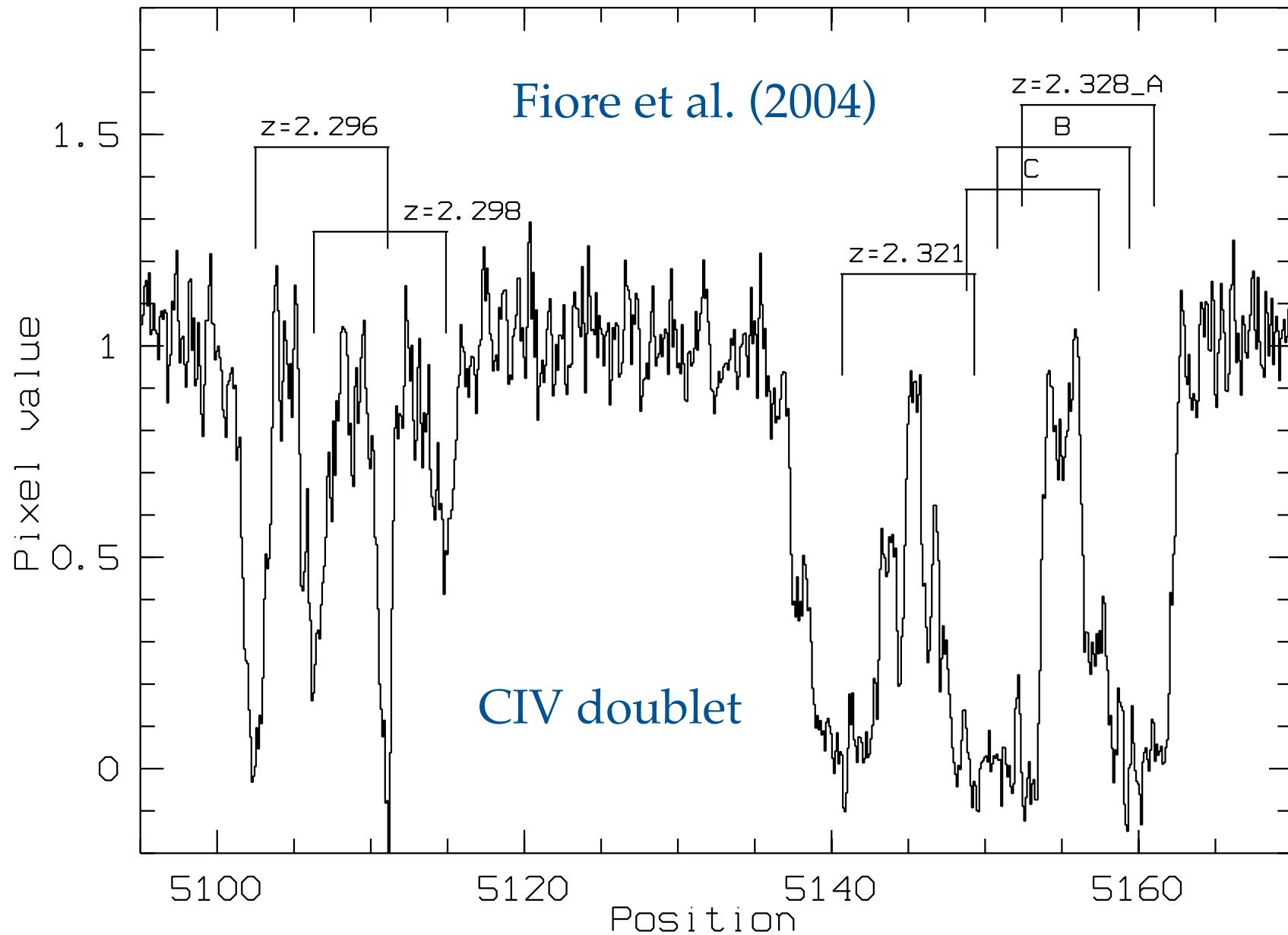
Starling et al. (2005)



TWO JETS IN GRB021004?



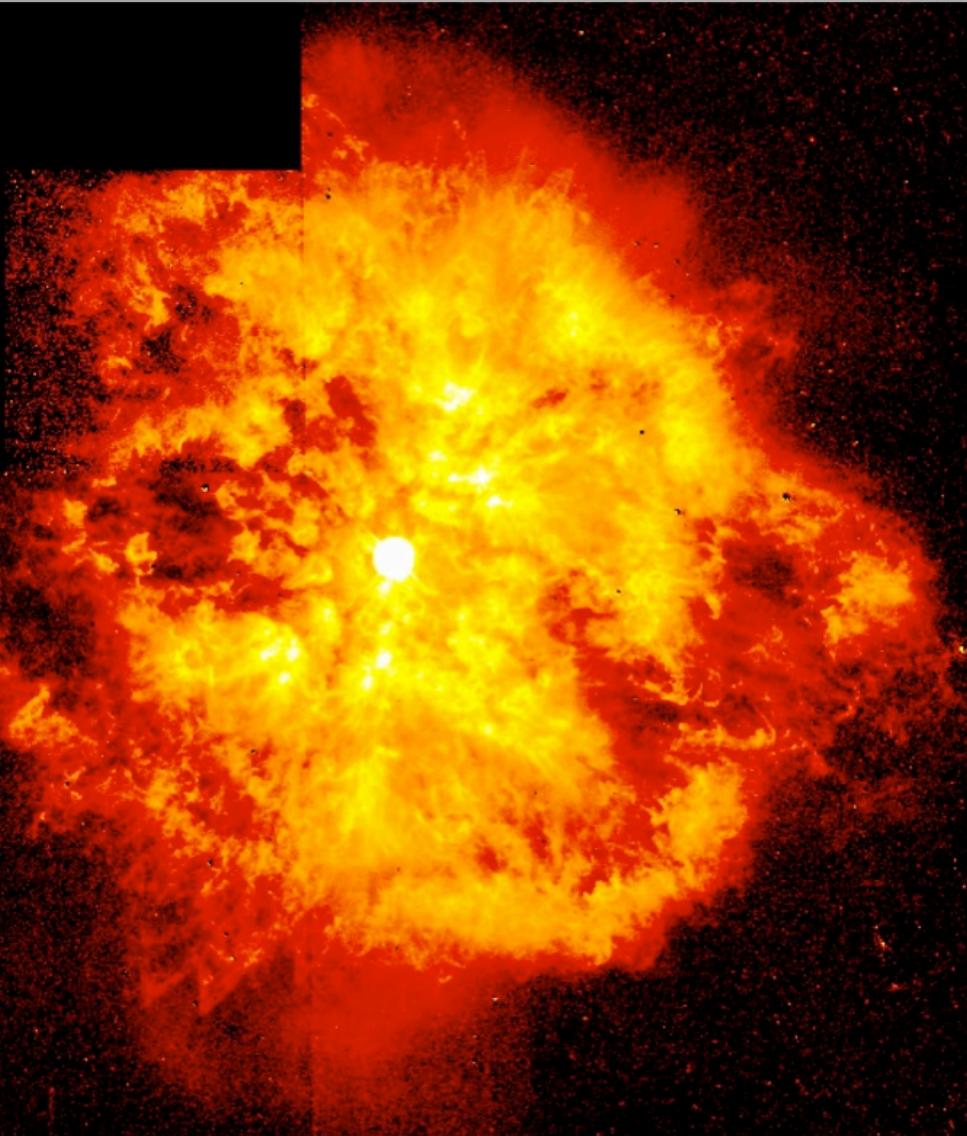
OUTFLOWS IN GRB 021004



OUTFLOWS IN GRB 021004

- absorption components with blueshifts up to ~3000 km/s (Schaefer et al., Mirabal et al., Møller et al., Starling et al., Fiore et al.)
- Wolf-Rayet progenitor provides natural explanation

WOLF-RAYET WIND



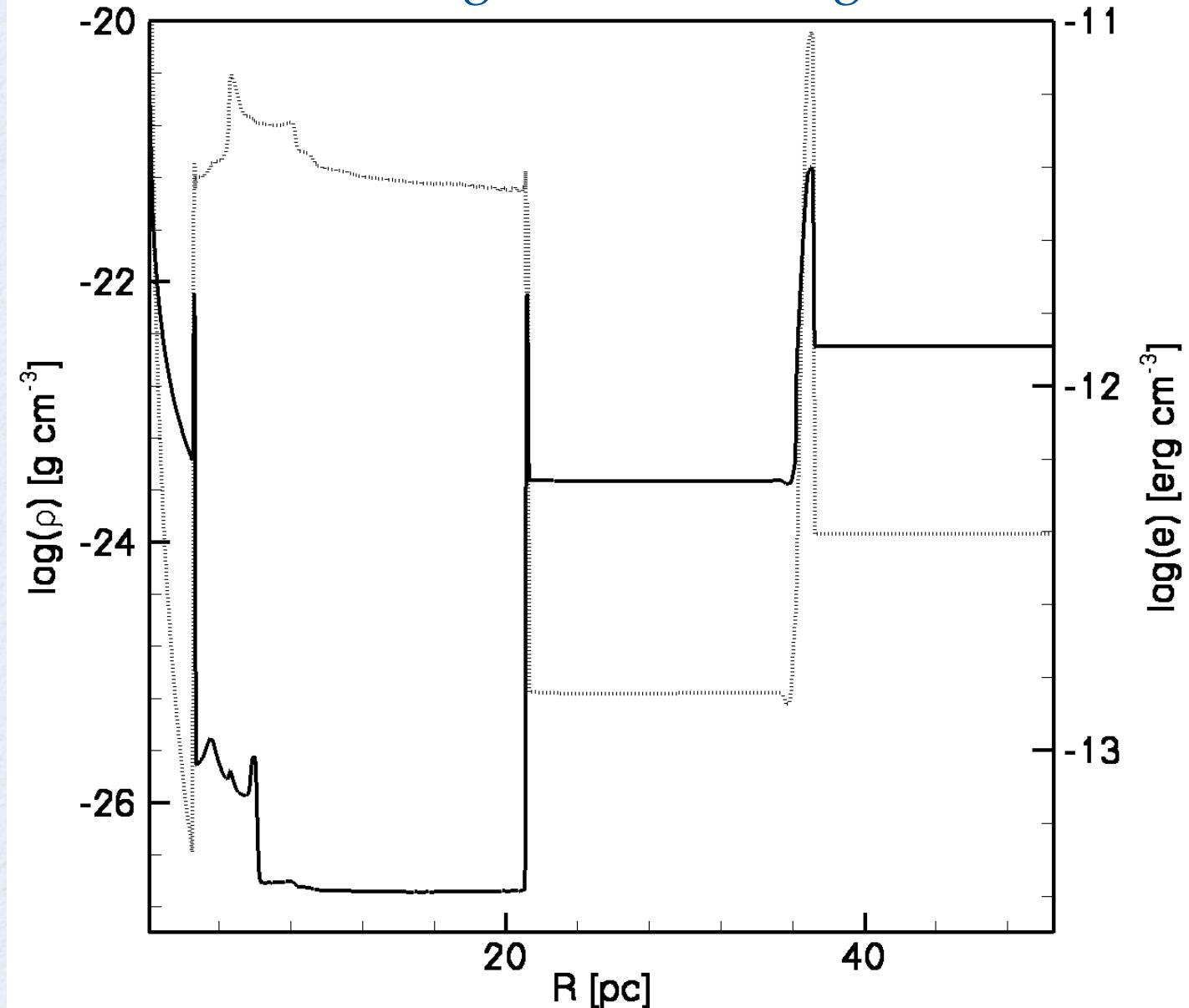
Nebula M1-67 around Star WR124
Hubble Space Telescope • WFPC2

- $dM \sim 10^{-5} M_{\odot} / \text{year}$
- wind velocity up to
 $\sim 3000 \text{ km/s}$
- blobs: up to $30 M_{\odot}$
- photosphere not visible

Grosdidier et al. (1998)

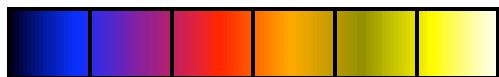
PRE-WR WIND STRUCTURE

van Marle, Langer & García-Segura (2005)

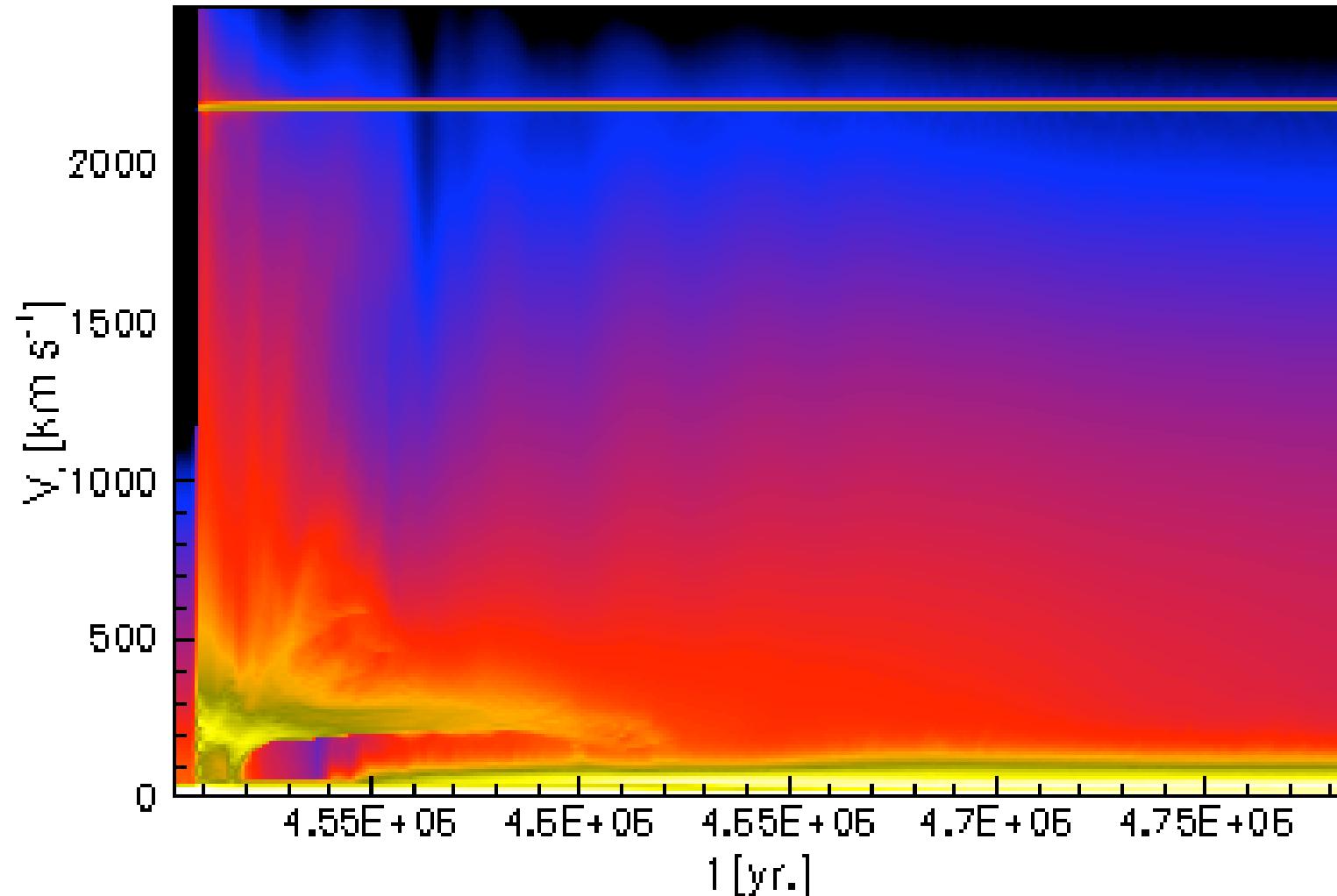


EXPECTED WIND FEATURES

van Marle, Langer & García-Segura (2005)



$\log(d_e(\Delta V = 1 \text{ km s}^{-1})) [\text{g cm}^{-3}]$: -12 -11 -10 -9 -8 -7 -5



OUTFLOWS IN GRB 021004

- absorption components with blueshifts up to ~3000 km/s (Schaefer et al., Mirabal et al., Møller et al., Starling et al., Fiore et al.)
- Wolf-Rayet progenitor provides natural explanation
- BUT: most afterglow spectra do not show high-velocity outflows

NOT ALL @ HIGH VELOCITY

GRB	velocities (km/s)	epoch (d)	lines
021004	600, 2700, 2900	0.5-6.6	Lya SIV CIV MgII AlIII ...
020813	4100	0.2	MgII MgI MnII
030226	2400	0.2-1.2	OI CII SIV SiII CIV FeII

000926	≤ 170	1.2	
010222	≤ 120	0.4-1.4	
030323	≤ 200	1.5	
050730	≤ 80	0.15	
050820	≤ 400	0.04	
.....			

CONCLUSIONS

on spectroscopy of GRB afterglows

- offers a relatively clean way to study foreground absorbers both in absorption and emission
- allows study of physical conditions in high-redshift massive star-forming regions (up to re-ionization?)
- can constrain massive-star progenitor evolution through detection of wind features